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ENVIRONMENTAL CONSIDERATIONS FOR EMERGING COPPER WINNING PROCESSES

by

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16. ABSTRACT

Fourteen processes for the production of copper were examined to evaluate their potential environmental impact, economics and energy requirements relative to reverberatory smelting as commonly practiced in the U.S. Because of limitations in data available for more recent process developments, detailed evaluations were completed for only four smelting processes: electric (two scenarios), Noranda (three scenarios), flash two scenarios each of the Outokumpo and INCO systems), and reverberatory (five scenarios). A computer program, developed by the Bureau under an independent effort was used to provide the estimates from published data.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The weak SO_2 emissions from primary copper have historically been, and continues to be, the barrier to achievement of SO_2 emission limitations in smelter localities. The ambient air quality standards are obtained only through the SCS (supplementary control system), i.e. by production curtailment in lieu of constant emissions controls. This document, one of a series that examines the weak SO_2 emission problem, was undertaken to examine capabilities of several alternative smelting and hydrometallurical metal winning technologies for the production of copper. The investigation was concentrated on the comparison of the degree of sulfur containment, energy consumption/savings and costs of a number of the newer, commercially employed pyrometallurgical smelting processes in combination with various types of final controls for sulfur containment. The emerging technologies for pyro- and hydrometallurgical processes are briefly discussed, but are not analyzed in as great of detail owing to the lack of basic data in the open literature.

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ABSTRACT

The results of an examination of 14 processes for the production of copper to determine their potential environmental impact, economics, and energy requirements are described in this report. Three of the objectives, air pollution potential, economics, and energy requirements, were met on models of four of the smelting processes, electric (two scenarios), Noranda (three scenarios), flash (two scenarios each of the Outokumpu and INCO versions), and reverberatory (five scenarios). An in-house developed computer program was used to calculate these results from published data on these processes.

When a reverberatory smelter without pollution controls is used as a standard for comparison with alternative processes

- unit production costs in cents per pound of copper, without byproduct credit, will increase from 34.6 to a range of 36.4 to 49.4 with an INCO flash smelter with an acid plant giving the lowest increase,
- estimates for byproduct credit shifts unit production cost to a lower range of 33.0 to 43.8 cents with INCO, Noranda, and Outokumpu flash smelters with acid plants giving cost in the lower end of the range,
- sulfur retention increased from 2.4 percent to a range of 64.5 to 96.2 percent with both an electric furnace with an acid plant and a reverberatory smelter treating reverberatory and converter gases in a citrate plant giving the highest retention, and
- energy requirements in million Btu per ton copper are 38.46 for the standard and range from 30.13 to 90.67 with both the Noranda and INCO smelters with acid plants using the least energy.

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SUMMARY

1. DESCRIPTION OF PROCESSES EVALUATED

The purpose of this study was to develop an estimate of the environmental pollution potential of emerging metal-winning processes in the copper industry and to provide technical background that might lead to programs to help solve pollution problems. Primary emphasis was given to air pollution potential, energy requirements, and process economics.

Some 14 processes were examined, and, in the order of their EPA-assigned priority, they were as follows:

1. Electric arc furnace smelting (two scenarios)--(1) SO_2 control by an acid plant, and (2) SO_2 control by a Bureau of Mines citrate process plant.
2. Noranda process (three scenarios)--(1) SO_2 control by an acid plant, (2) SO_2 control by a Bureau of Mines citrate process plant, and (3) SO_2 control by direct reduction.
3. Flash smelting (four scenarios)--(1) using preheated air with SO_2 control by an acid plant, (2) using preheated air with SO_2 control by a Bureau of Mines citrate process plant, (3) using oxygen with SO_2 control by an acid plant, and (4) using oxygen with SO_2 control by direct reduction.
4. Hecla-El Paso roasting-hydrometallurgical process.
5. Arbiter process.
6. Sherritt-Gordon-Cominco process.
7. Cymet process.
8. Duval "CLEAR" process.
9. Mitsubishi three-furnace process.
10. Oxygen-enriched reverberatory furnace.
11. Converter smelting.
12. Top blown rotary converter (TBRC).
13. Reverberatory smelting with DMA SO_2 process.

14. Conventional reverberatory process (five scenarios)--(1) no SO_2 control, (2) with reverberatory gas vented up the stack and converter gas going to an acid plant, (3) with converter gas going to an acid plant and reverberatory gases going to a Bureau of Mines citrate process plant, (4) with both converter and reverberatory gases going to a Bureau of Mines citrate process plant, and (5) using a roaster with both roaster and converter gases going to an acid plant.

As the study progressed, the main emphasis was directed towards the evaluation of the energy and economic aspects of the four most developed pyrometallurgical processes, specifically the electric furnace, Noranda process, flash furnace process, and variations of the conventional reverberatory furnace practice for sulfur dioxide control. This approach became necessary as the information required for analysis of the emerging hydrometallurgical and pyrometallurgical processes was not available.

It was found that none of the emerging hydrometallurgical process has been developed to a point where a meaningful analysis could be performed. It was also found that some of the newer smelting methods such as the three-furnace, oxygen-enriched reverberatory, converter smelter, top blown rotary converter, and DMA SO_2 processes have not yet been widely used and there was insufficient information for analysis. Quantitative data on emissions and effluents in the published literature were inadequate to account for the distribution of minor elements in any of the processes.

All of the processes that were evaluated were similar in that they were pyrometallurgical operations that produced blister copper which was cast into anodes and electrorefined. To enable a direct comparison of the various processes, each was assumed to produce 100,000 tons of electrorefined copper per year, starting from a hypothetical standard concentrate, the composition of which is given in Table 1. This hypothetical concentrate is a composite based on feed materials used by smelters in the Western United States, excluding custom smelters that treat complex ores, and the basis of its composition is shown in Appendix C.

TABLE 1. CHEMICAL COMPOSITION OF STANDARD CHALCOPYRITE CONCENTRATE (DRY BASIS)*

Constituent	Composition, pct
Cu	27.0
Fe	27.0
S	33.5
SiO_2	9.0
CaO	0.5
Other†	3.0

* Analysis of the standard concentrate was arrived at by averaging analyses of actual chalcopyrite concentrates used at a number of commercial smelters.

† "Other" includes oxygen, MgO, Al_2O_3, and minor elements.

Flowsheets for the processes evaluated indicate constant values for the SO_2 content of smelter gases. In actual operations there are cyclic variations in the SO_2 content of smelter gases due to intermittent charging and tapping of reverberatory furnaces, imperfect phasing of converters, and variations in matte grade. The values indicated are average flow for these fluctuating streams.

Material balance flowsheets for the processes show how the major elements in the concentrates, fluxes, and products are distributed. Included after all smelting operations (reverberatory, electric, Noranda, flash, converting, etc.) are electrostatic dust precipitators in which an estimated 10 percent dilution of the gas occurs because of leakage. Whenever available, information concerning the minor elements is given in the text.

Economic evaluations were made on modifications of four smelting processes for the purpose of making relative comparisons of capital and operating costs. For this reason, some of the minor operations normally conducted in a smelter, such as recycle of dust and scrap, have been omitted to simplify the flowsheets and calculations. These estimates do not include any interest or other charges for invested capital or allowances for federal taxes and profit. Also included as part of the economic evaluation are estimates of the total energy requirements.

Energy requirements for the production of a ton of copper by each of the processes evaluated were estimated with the help of reports on energy use patterns prepared by Battelle Columbus Laboratories.[1,2] Calculation methods equivalent to those used in the reports were used to make an itemized breakdown of total energy consumed in generating utilities and of the energy required for the raw materials. For raw materials, this included energy needed for mining and ore beneficiation, for smelting and refining of metals, for other raw materials used as part of the production process, and for transportation to processing and refining plants.

2. FINDINGS/CONCLUSIONS

In selecting a process for commercial application, more information than is given in this report is necessary. The amount of SO_2 removal necessary would be of primary importance, of course. Also, the actual overall cost would depend on the availability of a market, either internal or external, for the acid and/or sulfur produced. In most cases, where the use or sale of byproducts is possible, costs would be reduced by some indeterminate amount that would depend on local conditions. It should be recognized, however, that in instances where little or no use or sale of byproducts is possible, costs would be increased owing to the cost of storage or disposal. In the cases where neutralization of sulfuric acid is necessary, the disposal cost could make a significant change in the economics of the process. In these evaluations no credits or penalties were applied for disposal of byproducts so that all the processes could be compared on the same basis. Also, to be considered is the availability and cost of energy. In Finland, a country that must import fuel at high cost, a flash smelting process was adopted by Outokumpu. In this country, the availability of low-cost electric power at such sites as Copper Hill, Tenn., Inspiration, Ariz., and Anaconda, Mont., was a factor in the selection of electric furnace smelting. When smelters with acid plants for SO_2 control are compared, using a reverberatory smelter with an acid plant as a standard, the flash smelters, namely the Noranda, Outokumpu, and INCO versions, require about 30 percent less energy. Sulfur dioxide controls based on the citrate process or on direct reduction will increase energy requirements by factors ranging from 1.5 to 2.0.

Estimated costs and energy requirements were prepared for recovering copper from chalcopyrite concentrates by some 14 scenarios of 4 basic processes. Data for these estimates are presented in Tables 2 and 3.

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[1] Battelle Columbus Laboratories (Columbia, Ohio). Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4--Energy Data and Flowsheets, High-Priority Commodities), June 27, 1975, 187 pp.; available from National Technical Information Service, Springfield, Va., PB 245 759/AS.

[2] Ibid. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 7--Summary of the results of phases 4, 5, and 6), Sept. 21, 1976, 24 pp.; available from National Technical Information Service, Springfield, Va., PB 261151/AS.

TABLE 2. ESTIMATED CAPITAL COST, OPERATING COST, AND ENERGY REQUIREMENTS*†

Process	Type of SO_2 control	Fixed capital, dollars	Working capital, dollars	Annual operating cost, dollars	Energy requirement, million Btu/ton Cu
Noranda process	Acid plant	305,118,000	16,613,000	74,101,000	30.13
Do.	Citrate plant	341,002,000	21,185,000	92,978,000	66.90
Do.	Direct reduction	304,701,000	20,979,000	91,550,000	85.14
Outokumpu flash	Acid plant	300,992,000	16,639,000	74,122,000	30.88
Do.	Citrate plant	330,456,000	21,320,000	93,022,000	68.07
INCO flash	Acid plant	286,086,000	16,426,000	72,891,000	33.19
Do.	Direct reduction	311,605,000	22,049,000	96,065,000	90.67
Electric smelting	Acid plant	300,529,000	18,211,000	80,021,000	44.97
Do.	Citrate plant	315,140,000	22,027,000	95,350,000	81.69
Reverberatory	None	261,028,000	15,679,000	69,193,000	38.46
Do.	Converter gas to acid plant	313,267,000	18,250,000	80,747,000	43.56
Do.	Converter gas to acid plant, reverberatory gas to citrate plant	348,784,000	21,204,000	93,241,000	58.38
Do.	Converter and reverberatory gases to citrate plant	334,686,000	22,768,000	98,725,000	81.67
Do.	Roaster and converter gases to acid plant	307,077,000	17,918,000	79,257,000	41.93

* Estimates are based on 1980 costs without allowance for escalation during construction period and do not include interest on invested capital, federal taxes, or profit. Capacity basis is 100,000 tons per year of electrorefined copper.

† See appendix for methodology and costing basis.

TABLE 3. SUMMARY OF PROCESSES EVALUATED*

Process	Type of SO_2 control	Total sulfur retention†	Sulfur recovered,† pct	Byproduct produced, tpd		Estimated overall cost, cents/lb/Cu (No byproduct credit)
				Sulfuric acid	Sulfur	
Noranda process	Acid plant	437.8	95.6	1,269.4	0	37.1
Do.	Citrate plant	437.5	95.5	0	410.5	46.5
Do.	Direct reduction	398.0	86.9	0	375.2	45.8
Outokumpu flash	Acid plant	364.6	95.9	1,050.6	0	37.1
Do.	Citrate plant	364.3	95.8	0	339.8	46.5
INCO flash	Acid plant	367.2	95.9	1,054.0	0	36.4
Do.	Direct reduction	333.8	87.2	0	311.6	48.0
Electric smelting	Acid plant	368.3	96.2	1,043.2	0	40.0
Do.	Citrate plant	357.3	93.3	0	337.1	47.7
Reverberatory	None	9.1	2.4	0	0	34.6
Do.	Converter gas to acid plant	246.9	64.5	690.8	0	40.4
Do.	Converter gas to acid plant, reverberatory gas to citrate plant	368.3	96.2	690.8	114.1	46.6
Do.	Converter and reverberatory gas to citrate plant	367.8	96.1	0	337.06	49.4
Do.	Roaster and converter gas to acid plant	292.5	76.4	823.0	0	39.6

* Estimates are based on 1980 costs without allowance for escalation during construction period and do not include interest on invested capital, federal taxes, or profit. Capacity basis is 100,000 tons per year of electrorefined copper.

† Total sulfur retention includes sulfur in H_2SO_4, $CaSO_4$, slag, tailings, sulfur product, and $Na_2SO_4 \cdot 10H_2O$.

TABLE 4. ESTIMATED EFFECT OF BYPRODUCT CREDIT ON OPERATING COST

Process	Type of SO_2 control	Annual operating cost, dollars	Byproduct* credit, dollars	Annual operating cost with byproduct credit, dollars	Estimated overall cost, cents/lb Cu		Reduction in cost	
					No credit	With credit	Cents	Percent
Noranda process	Acid plant	74,101,000	6,956,000	67,145,000	37.1	33.6	3.5	9.4
Do.	Citrate plant	92,978,000	11,248,000	81,730,000	46.5	40.9	5.6	12.0
Do.	Direct reduction	91,550,000	10,281,000	81,259,000	45.8	40.6	5.2	11.4
Outokumpu flash	Acid plant	74,122,000	6,934,000	67,188,000	37.1	33.6	3.5	9.4
Do.	Citrate plant	93,022,000	11,213,000	81,809,000	46.5	40.9	5.6	12.0
INCO flash	Acid plant	72,891,000	6,956,000	65,935,000	36.4	33.0	3.4	9.3
Do.	Direct reduction	96,065,000	10,283,000	85,782,000	48.0	42.9	5.1	10.6
Electric smelting	Acid plant	80,021,000	6,885,000	73,136,000	40.0	36.6	3.4	8.5
Do.	Citrate plant	95,350,000	11,124,000	84,226,000	47.7	42.1	5.6	11.7
Reverberatory	None	69,193,000	-	69,193,000	34.6	34.6	0	0
Do.	Converter gas to acid plant	80,747,000	4,559,000	76,188,000	40.4	38.1	2.3	5.7
Do.	Converter gas to acid plant, reverberatory gas to citrate plant	93,241,000	8,325,000	84,916,000	46.6	42.5	4.1	8.8
Do.	Converter and reverberatory gas to citrate plant	98,725,000	11,123,000	87,602,000	49.4	43.8	5.6	11.3
Do.	Roaster and converter gas to acid plant	79,257,000	5,432,000	73,825,000	39.6	36.9	2.7	6.8

* Based on \$20.00 per ton for H_2SO_4 and \$100.00 per ton for elemental sulfur.

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Costs range from a low of 34.6 cents per pound for a conventional smelter with no sulfur dioxide controls to 49.4 cents per pound for a conventional smelter using a citrate process plant to treat both the reverberatory and converter gases. If this conventional reverberatory smelter with no sulfur dioxide controls is used as a standard for comparison, the various systems for controlling emissions will be found to increase capital investment over a range of 30 to 34 percent and costs for producing copper over a range of 5 to 43 percent. The lowest cost smelter with sulfur dioxide controls was an INCO flash operation with an acid plant (36.4 cents per pound). Because of variations in local demands, already mentioned, the effect of byproduct credits was not included in our computer program. However, a rough comparison of these effects was made on the basis of assigned values of $20 per ton for sulfuric acid and $100 per ton for elemental sulfur. The effect of these byproduct values is shown in Table 4. As expected, byproduct values shift the unit production costs of copper to a lower range of 33 to 43.8 cents per pound, but they also have a leveling effect in that costs for the Noranda smelter with an acid plant and the INCO and Outokumpu flash smelter with acid plants were in the lower end of the cost range (33.4 to 33.6 cents per pound).

Energy requirements ranged from about 30 million Btu per ton of copper for a Noranda smelter with an acid plant to more than 90 million Btu per ton of copper for an INCO flash smelter using direct reduction of sulfur dioxide. When compared with a reverberatory smelter with an acid plant, the Noranda, Outokumpu, and INCO smelters with acid plants require about 30 percent less energy. Sulfur dioxide controls based on the citrate process for an Outokumpu smelter or on direct reduction on an INCO smelter will increase energy requirements by 50 to 100 percent, respectively.

None of the emerging hydrometallurgical processes are in commercial production, and not enough details of these processes are available for technical or economic evaluations.

3. NORANDA PROCESS

The Noranda process[3-5] is a continuous smelting process that operates on pelletized concentrates and can be controlled to accept a wide range of feed grades and yield either blister copper or high-grade matte. Sulfur dioxide in the offgas ranges from 5.5 percent for an operation using air to 21 percent when oxygen-enriched air is used. In either case, the gas can be used to make sulfuric acid.

---

[3] Themelis, N. J., G. C. McKerrow, P. Tarassoff, and G. D. Hallett. The Noranda Process. Pres. at 100th Ann. AIME Meeting, New York City, Mar. 1-4, 1971.

[4] McKerrow, G. C., G. D. Hallett, and P. Tarassoff. Oxygen in the Noranda Process. Pres. at meeting of the Arizona sec. of the AIME, Tucson, Ariz., Dec. 3, 1973.

[5] Bailey, J. B. W., R. R. Beck, G. D. Hallett, C. Washburn, and A. J. Weddick. Oxygen Smelting in the Noranda Process. Pres. at the 104th Ann. AIME Meeting, New York City, Feb. 16-20, 1975.

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A schematic diagram in Figure 1 shows that the reactor is a rotatable, horizontal, cylindrical furnace with fuel burners at each end and an offgas discharge mouth in the center. The charge and fluxes are fed at one end of the furnace by a belt slinger that spreads them over the reaction zone where conversion occurs by the injection of air or oxygen-enriched air through tuyeres. These tuyeres can be brought out of the bath by rotation of the furnace.

The bath in the furnace can consist of either two or three layers, matte and slag, or metallic copper, matte, and slag. In the center of the reactor is a sump-like depression from which copper or matte can be recovered through tapholes. Slag moves to the other end of the furnace where additional settling occurs as it is heated by a burner and is removed through a taphole at the end wall of the furnace. This slag, containing 10 to 12 percent copper, is cast into large cakes 4 to 6 feet in diameter and 1-1/2 feet thick, slow cooled, and then crushed and milled to recover a high-grade concentrate containing about 50 percent copper through flotation. Slag concentrate is recycled and makes up about 15 percent of the charge to the furnace. Milled tailings contain less than 0.5 percent copper.

The distribution of minor impurities, lead, arsenic, antimony, zinc, and bismuth, has been reported for a Noranda operation producing a 72 percent copper matte.[6] This report shows that matte produced by the Noranda process contains higher levels of minor impurities than matte produced in a reverberatory furnace. When matte is produced in a Noranda furnace, the impurity content of the converter product (blister copper) will depend on the impurity content of the matte and on the grade of the matte. A high impurity content would require a long blowing time and the matte grade would have to be low (high in sulfur). By varying the matte grade it should be possible to produce a blister copper similar to that produced from a reverberatory matte. In either case the bulk of the impurities end up in the slag or fine dust. All of the gas, with the exception of the small amount from the anode furnace, is cleaned and processed for recovery of acid. Therefore, the impurities should be captured as acid plant sludge, slag, or treatable dust.

For the past 2 years Kennecott Copper Corp.'s Utah Copper Division has been operating a new smelter that uses a version of the Noranda process to make high-grade matte. No other smelter in this country has revealed plans for using this process.

Economic evaluations were made of three scenarios of a Noranda-type smelter that makes blister copper directly, one using a sulfuric acid plant to remove sulfur dioxide from the offgas, a second using a Bureau of Mines citrate process plant to produce elemental sulfur, and a third using a plant for the direct reduction of sulfur dioxide to elemental sulfur. In these evaluations, the only difference is in the treatment of the offgas. All of the intermediate and final products are the same. These evaluations differ

[6] Mackey, P. J., G. C. McKerrow, and P. Tarassoff. Minor Elements in the Noranda Process. Pres. at the 104th Ann. AIME Meeting, New York City, Feb. 16-20, 1975.

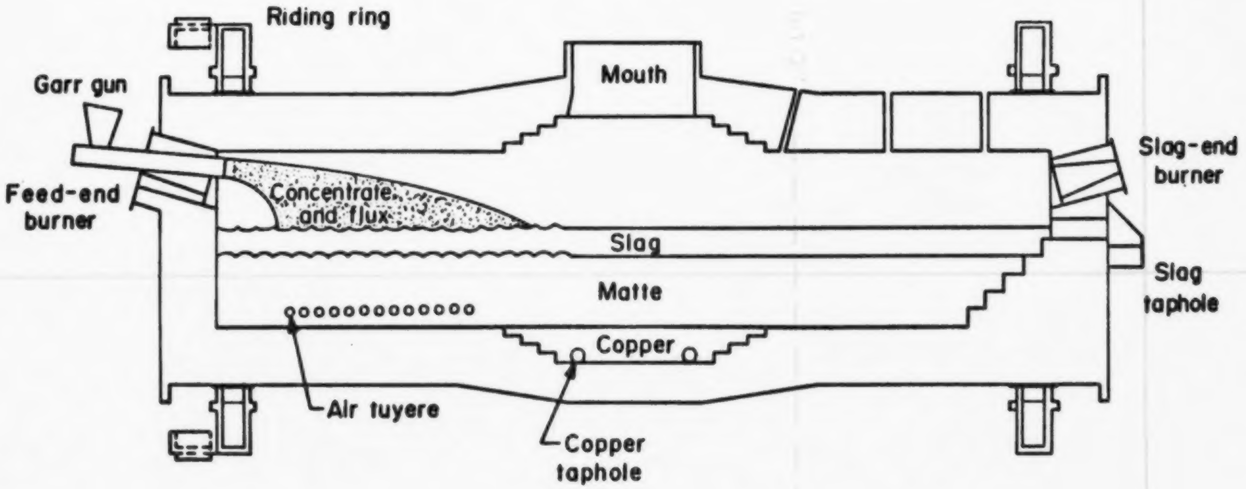
Riding ring
Garr gun
Mouth
Slag-end burner
Feed-end burner
Concentrate and flux
Slag
Matte
Slag taphole
Copper
Air tuyere
Copper taphole

FIGURE 1 - Schematic diagram of Noranda Process reactor

from the others in that the smelter is assumed to operate 274 days per year while the tankhouse operates 330 days per year. This difference is due to the fact that the Noranda furnace requires more down-time for maintenance. Total annual copper production is the same as in the other evaluations. In order to show a balanced distribution, the materials balance flowsheets were based on 274 operating days for all operations.

Concentrate is fed at a rate of 1,366.7 tons per day (on a dry basis) together with 120.7 tons per day of siliceous flux, and 237.2 tons per day of recycle slag concentrate. Enriched air containing 50 percent O_2 and natural gas is used in the burners. Enriched air containing 34 percent O_2 is introduced through tuyeres in the bottom of the furnace. This Noranda furnace produces 373.2 tons per day of blister copper analyzing 97.8 percent Cu and 2.0 percent S. Offgas containing 20.9 percent SO_2 goes to a sulfur recovery operation.

A slag product, 1,024.1 tons per day, containing 12 percent Cu, goes to a flotation operation. The flotation operation yields 237.2 tons per day of a slag concentrate containing 50 percent Cu, and 786.9 tons per day of a tailings product containing 0.51 percent Cu.

The blister copper is treated in an anode furnace for removal of excess sulfur and cast into anodes. The anodes go to the electrolytic cells in the refinery where 303 tons per day (100,000 tons per 330-day operating year) of electrolytic copper is produced.

Noranda Process--Gas to Acid Plant

The first evaluation is for a Noranda smelter operating as described, with the offgas containing 20.9 percent SO_2 going to a 1,400-ton-per-day double contact acid plant that recovers 1,269.4 tons per day byproduct acid. This represents a recovery of 90.22 percent of the 457.9 tons per day of sulfur in the feed as sulfuric acid. The balance of the sulfur is distributed as follows, in percent: 0.15 in slag (flotation tailing), 1.81 in fugitive gas leaked within smelter, 4.82 as neutralized acid sludge, and 2.60 vented up the stack (1.64 from anode furnace and 0.96 from acid plant tail gas). A materials balance flowsheet for this process is shown in Figure 2, and costs and energy requirements are presented in Tables 5 through 7.

Noranda Process--With Gas to Citrate Process Plant

In this example, a Bureau of Mines citrate process plant is used to remove SO_2 in the offgas. This modification recovers 89.67 percent of the 457.9 tons per day sulfur in the feed as elemental sulfur. The balance of the sulfur is distributed as follows, in percent: 0.15 in slag (flotation tailing), 1.81 in fugitive gas leaked within smelter, 4.82 as neutralized acid sludge, 0.95 as Glauber's salt, and 2.60 vented up the stack (1.64 from anode furnace and 0.96 from citrate plant tail gas). A materials balance flowsheet for this process is shown in Figure 3 and costs and energy requirements are presented in Tables 8 through 10.

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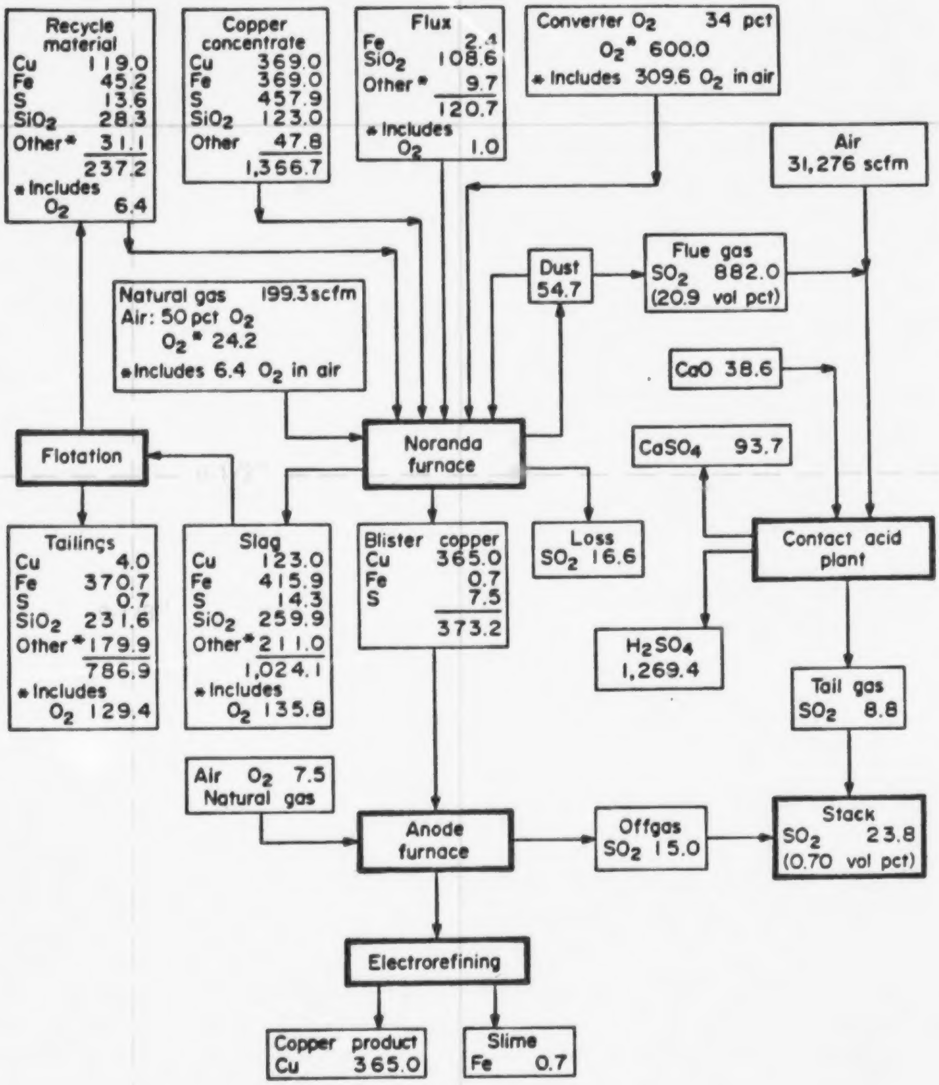
Recycle material
Cu 119.0
Fe 45.2
S 13.6
SiO_2 28.3
Other* 31.1
237.2
* Includes O_2 6.4
Copper concentrate
Cu 369.0
Fe 369.0
S 457.9
SiO_2 123.0
Other 47.8
1,366.7
Flux
Fe 2.4
SiO_2 108.6
Other* 9.7
120.7
* Includes O_2 1.0
Converter O_2 34 pct
O_2* 600.0
* Includes 309.6 O_2 in air
Air
31,276 scfm
Dust
54.7
Flue gas
SO_2 882.0
(20.9 vol pct)
Natural gas 199.3 scfm
Air: 50 pct O_2
O_2* 24.2
* Includes 6.4 O_2 in air
CaO 38.6
Flotation
Noranda furnace
$CaSO_4$ 93.7
Tailings
Cu 4.0
Fe 370.7
S 0.7
SiO_2 231.6
Other* 179.9
786.9
* Includes O_2 129.4
Slag
Cu 123.0
Fe 415.9
S 14.3
SiO_2 259.9
Other* 211.0
1,024.1
* Includes O_2 135.8
Blister copper
Cu 365.0
Fe 0.7
S 7.5
373.2
Loss
SO_2 16.6
Contact acid plant
H_2SO_4
1,269.4
Tail gas
SO_2 8.8
Air O_2 7.5
Natural gas
Anode furnace
Offgas
SO_2 15.0
Stack
SO_2 23.8
(0.70 vol pct)
Electrorefining
Copper product
Cu 365.0
Slime
Fe 0.7

FIGURE 2 - Material balance and flow diagram for Noranda process with a sulfuric acid plant for the offgas. (tons per day)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)
TYPING GUIDE SHEET

TABLE 5. - Annual operating cost, $, of unit operations for Noranda copper smelter with acid plant

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	PCT
DIRECT COST				
MATERIALS				
SILICA FLUX	33071.8 TON	10.00	330700.	.45
K AMYL XANTHATE	123300.0 LB	1.00	123300.	.17
MIC	164400.0 LB	.39	64100.	.09
LEAD ANODE	105.6 TON	3089.00	326300.	.44
GLUE	5049.8 LB	.90	4500.	.01
GOULAC	251777.8 LB	.15	37800.	.05
H2SO4	294.1 TON	20.00	5900.	.01
LIME	10592.5 TON	53.40	565600.	.75
TOTAL			1458200.	1.97
UTILITIES				
ELECTRICITY	150722.9258 MKWHR	40.00	6028900.	8.14
NATURAL GAS, CONSUMED	1325305.5 MCF	3.15	4174700.	5.63
WATER, PROCESS	110650.3 MGAL	.34	37600.	.05
WATER, COOLING	997769.6 MGAL	.06	59900.	.08
STEAM	1053600.4 MLB	4.22	4446200.	5.99
CREDIT FOR STEAM	1053600.0 MLB	-4.22	-4446200.	-5.99
TOTAL			10301100.	13.90
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4253200.	5.74
SUPERVISION .150			637900.	.86
TOTAL, D			4891100.	6.60
PLANT MAINTENANCE				
LABOR			4354500.	5.88
SUPERVISION .200			870800.	1.18
MATERIALS			6531400.	8.81
TOTAL, M			11756700.	15.87
PAYROLL OVERHEAD .600(PAYROLL)			6069800.	8.19
OPERATING SUPPLIES, S .200(M)			2351400.	3.17
TOTAL DIRECT COST			36828300.	49.70
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			7599700.	10.26
FIXED COST				
TAXES AND INSURANCE .020			5263600.	7.10
DEPRECIATION 12.500 YR			24409400.	32.94
TOTAL			29673000.	40.04
TOTAL ANNUAL OPERATING COST			74101000.	100.00

SULFUR REMOVAL = 95.4%, CU RECOVERY= 98.9%
REVISED COST (ASARCO)
CU- 21. 1 6
CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
ACID PLANT, FLOTATION,O2 PLANT

JULY 31, 1980

COPPER 100000.0 TON PER YEAR

ESTIMATE 198.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	122000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	4141000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	12350000.
TOTAL	16613000.

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TABLE 6. - Summary of costs and operating personnel for Noranda copper smelter with acid plant

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	22851100.	5398900.	7.29	.02699
NORANDA SMELTING	34.0	86123100.	19421700.	26.21	.09711
SLAG CRUSH, GRIND, FLOAT	17.0	14953600.	4532600.	6.12	.02266
ANODE CASTING	17.0	15967700.	4542600.	6.13	.02271
ELECTROLYTIC REFINING	106.0	73112100.	26218000.	35.38	.13109
CONTACT ACID PLANT	12.0	25476200.	8482400.	11.45	.04241
OXYGEN PLANT	8.0	11612800.	5504800.	7.43	.02752
TOTAL, T		250096600.			
FACILITIES,.100(T)		25009700.			
UTILITIES,.120(T)		30011700.			
TOTAL FIXED CAPITAL		305118000.			
WORKING CAPITAL		16613000.			
TOTAL CAPITAL	213.0	321731000.	74101000.	100.00	.37050

```
SULFUR REMOVAL = 95.4%, CU RECOVERY= 98.9%
     REVISED COST (ASARCO)
             CU- 21.  1 6
CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
     ACID PLANT, FLOTATION,O2 PLANT

                JULY 31, 1980

       14.41722, $/ TON    CU CONCENTRATE
      189.93064, $/ TON    BLISTER CU
       16.15305, $/ TON    SLAG
       44.42345, $/ TON    BLISTER CU
      262.17964, $/ TON    COPPER
         .01219, $/LB      H2SO4
         .03259, $/LB      OXYGEN


COPPER                    100000.0 TON   PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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TABLE 7. - Summary of energy requirements for Noranda copper smelter with acid plant

```
------------------------------------------------------------------------
                                                    MMBTU/YR   PERCENT
------------------------------------------------------------------------
UNIT OPERATION
  CRUSHING     AND STORAGE                              8752.      .29
  NORANDA      SMELTING                                82318.     2.73
  SLAG CRUSH, GRIND, FLOAT                            146394.     4.86
  ANODE        CASTING                                165073.     5.48
  ELECTROLYTIC REFINING                              1685022.    55.92
  CONTACT ACID PLANT                                  566123.    18.79
  OXYGEN PLANT                                        359625.    11.93
------------------------------------------------------------------------
    TOTAL FOR PLANT                                  3013308.   100.00

ENERGY SOURCE
  ELECTRICITY LOW V                                   153589.     5.10
  ELECTRICITY INT V                                  1243971.    41.28
  ELECTRICITY LINE V                                  185031.     6.14
  NATURAL GAS                                        1325305.    43.98
  STEAM                                              1475041.    48.95
  STEAM                                             -1475040.   -48.95
  SILICA FLUX                                           1389.      .05
  N AMYL XANTHATE                                       2466.      .08
  MIC                                                   3288.      .11
  LEAD ANODE                                            2852.      .09
  GLUE                                                   101.      .00
  GOULAC                                                5036.      .17
  H2SO4                                                  244.      .01
  LIME                                                 90036.     2.99
------------------------------------------------------------------------
    TOTAL FOR PLANT                                  3013308.   100.00

UNIT ENERGY REQUIREMENT       30.1331 MMBTU PER  TON  COPPER
```

```
SULFUR REMOVAL = 95.4%, CU RECOVERY= 98.9%
     REVISED COST (ASARCO)
              CU- 21.  1 6
CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
     ACID PLANT, FLOTATION,O2 PLANT
              JULY 31, 1980

COPPER                   100000.0 TON   PER YEAR
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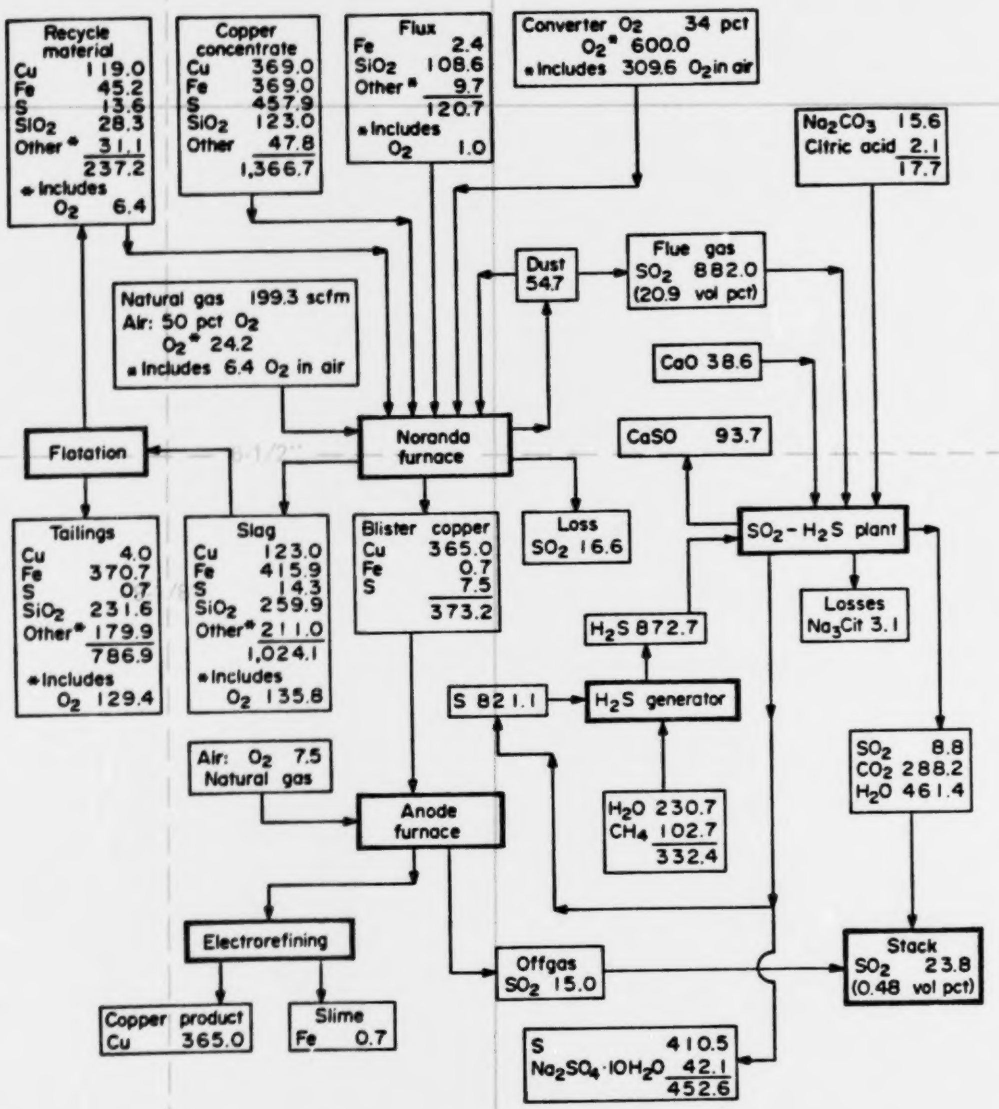
Recycle material
Cu 119.0
Fe 45.2
S 13.6
SiO_2 28.3
Other* 31.1
237.2
*Includes
O_2 6.4
Copper concentrate
Cu 369.0
Fe 369.0
S 457.9
SiO_2 123.0
Other 47.8
1,366.7
Flux
Fe 2.4
SiO_2 108.6
Other* 9.7
120.7
*Includes
O_2 1.0
Converter O_2 34 pct
O_2* 600.0
*Includes 309.6 O_2 in air
Na_2CO_3 15.6
Citric acid 2.1
17.7
Dust 54.7
Flue gas
SO_2 882.0
(20.9 vol pct)
Natural gas 199.3 scfm
Air: 50 pct O_2
O_2* 24.2
*Includes 6.4 O_2 in air
CaO 38.6
Flotation
Noranda furnace
CaSO 93.7
Tailings
Cu 4.0
Fe 370.7
S 0.7
SiO_2 231.6
Other* 179.9
786.9
*Includes
O_2 129.4
Slag
Cu 123.0
Fe 415.9
S 14.3
SiO_2 259.9
Other* 211.0
1,024.1
*Includes
O_2 135.8
Blister copper
Cu 365.0
Fe 0.7
S 7.5
373.2
Loss
SO_2 16.6
SO_2-H_2S plant
Losses
Na_3Cit 3.1
H_2S 872.7
S 821.1
H_2S generator
SO_2 8.8
CO_2 288.2
H_2O 461.4
Air: O_2 7.5
Natural gas
Anode furnace
H_2O 230.7
CH_4 102.7
332.4
Electrorefining
Offgas
SO_2 15.0
Stack
SO_2 23.8
(0.48 vol pct)
Copper product
Cu 365.0
Slime
Fe 0.7
S 410.5
$Na_2SO_4 \cdot 10H_2O$ 42.1
452.6

FIGURE 3.-Material balance and flow diagram for Noranda process with a Bureau of Mines citrate process for the offgas. (tons per day)

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TABLE 8. - Annual operating costs, $, of unit operations for Noranda copper smelter with Bureau of Mines citrate process

```
------------------------------------------------------------------------
                                 ANNUAL           UNIT       OPERATING COST,
                              CONSUMPTION         COST           $        PCT
------------------------------------------------------------------------
DIRECT COST
  MATERIALS
    SILICA FLUX                 33071.0 TON      10.00       330700.     .36
    N AMYL XANTHATE            123300.0 LB        1.00       123300.     .13
    MIC                        164400.0 LB         .39        64100.     .07
    LEAD ANODE                    105.6 TON    3089.00       326300.     .35
    GLUE                         5049.0 LB         .90         4500.     .00
    GOULAC                     251777.0 LB         .15        37800.     .04
    H2SO4                         294.1 TON      20.00         5900.     .01
    LIME                        10592.5 TON      53.40       565600.     .61
    CITRIC ACID                   562.5 TON    1360.00       765000.     .82
    SODA ASH                     4286.0 TON      60.00       257100.     .28
    KEROSINE                    90613.9 GAL        .95        86100.     .09
                                                        ------------ ------
        TOTAL                                                2566400.   2.76
  UTILITIES                                             ============ ======
    ELECTRICITY             120481.1211 MKWHR    40.00      4819200.   5.18
    NATURAL GAS, CONSUMED     4275988.2 MCF       3.15     13469400.  14.49
    WATER, PROCESS              86325.2 MGAL       .34        29400.    .03
    WATER, COOLING            7008340.9 MGAL       .06       420500.    .45
    STEAM                     1737910.0 MLB       4.22      7334000.   7.88
    CREDIT FOR STEAM          1053600.0 MLB      -4.22     -4446200.  -4.77
                                                        ------------ ------
        TOTAL                                               21626300.  23.26
  DIRECT LABOR                                          ============ ======
    LABOR   9.600/MAN HOUR                                   4353000.   4.68
    SUPERVISION   .150                                        653000.    .70
                                                        ------------ ------
        TOTAL, D                                             5006000.   5.38
  PLANT MAINTENANCE                                     ============ ======
    LABOR                                                    4862500.   5.23
    SUPERVISION   .200                                        972300.   1.05
    MATERIALS                                                7293500.   7.84
                                                        ------------ ------
        TOTAL, M                                            13128300.  14.12
  PAYROLL OVERHEAD   .600(PAYROLL)                           6504500.   7.00
  OPERATING SUPPLIES, S   .200(M)                            2625700.   2.82
                                                        ============ ======
        TOTAL DIRECT COST                                   51457200.  55.35
INDIRECT COST
  ADMINISTRATION AND OVERHEAD   .400(D+M+S)                  8304000.   8.93
FIXED COST                                              ============ ======
  TAXES AND INSURANCE   .020                                 5936600.   6.38
  DEPRECIATION 12.500 YR                                    27280200.  29.35
                                                        ------------ ------
        TOTAL                                               33216800.  35.73
                                                        ============ ======
        TOTAL ANNUAL OPERATING COST                         92978000. 100.00
```

```
CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
     CITRATE PLANT, FLOTATION
              CU- 21.  2 6
12.5 YR DEPRECIATION
     ADJUSTED COST (ASARCO)

                  JULY 31, 1980


COPPER                         100000.0 TON   PER YEAR


ESTIMATE  221.0 MAINT. MEN,  10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH


               WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS =
  (TOTAL ANNUAL MATERIAL COST)/12            214000.
1 MONTH'S OUT-OF-POCKET EXPENSE =
  (TOTAL AN OP COST-DEPRECIATION)/12        5475000.
2 MONTH'S PRODUCT INVENTORY =
  (TOTAL ANNUAL OPERATING COST)/6          15496000.
                                       -------------
   TOTAL                                   21185000.
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TABLE 9. - Summary of costs and operating personnel for Noranda copper smelter with Bureau of Mines citrate process

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	22851100.	5399500.	5.81	.02700
NORANDA SMELTING	34.0	86123100.	19356600.	20.82	.09678
SLAG CRUSH, GRIND, FLOAT	17.0	14953600.	4505100.	4.85	.02253
ANODE CASTING	17.0	15967700.	4507300.	4.85	.02254
ELECTROLYTIC REFINING	106.0	73112100.	25550300.	27.48	.12775
GAS COOLING & CLEANING	2.1	5876600.	1962500.	2.11	.00981
ABSORPTION	2.1	1419400.	1883700.	2.03	.00942
SULFUR PRECIPITATION	4.2	1447900.	622900.	.67	.00311
SULFUR RECOVERY	2.1	8517200.	2236500.	2.41	.01118
H2S GENERATION	4.3	34325200.	21355600.	22.97	.10678
SODIUM SULFATE REMOVAL	2.2	3347100.	1110000.	1.19	.00555
OXYGEN PLANT	8.0	11612800.	4488000.	4.83	.02244
TOTAL, T		279553800.			
INITIAL REAGENTS, IR = 242700.					
FACILITIES,.100(T-IR)		27931100.			
UTILITIES,.120(T-IR)		33517100.			
TOTAL FIXED CAPITAL		341002000.			
WORKING CAPITAL		21185000.			
TOTAL CAPITAL	218.0	362187000.	92978000.	100.00	.46489

CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
CITRATE PLANT, FLOTATION
CU- 21. 2 6
12.5 YR DEPRECIATION
ADJUSTED COST (ASARCO).

JULY 31, 1980

14.41882,	$/ TON	CU CONCENTRATE
189.29401,	$/ TON	BLISTER CU
16.05504,	$/ TON	SLAG
44.07824,	$/ TON	BLISTER CU
255.50265,	$/ TON	COPPER
.14388,	$/ MSCF	FLUE GAS, 20.9%SO2
.00787,	$/LB	SULFUR
.00260,	$/LB	SULFUR
.00934,	$/LB	SULFUR
.04466,	$/LB	H2S
.04807,	$/LB	GLAUBER SALT
.02657,	$/LB	OXYGEN

COPPER 100000.0 TON PER YEAR

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EPA-287 (Cin.)
(4-76)

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TABLE 10. - <u>Summary of energy requirements for Noranda copper smelter with Bureau of Mines citrate process</u>

```
CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
     CITRATE PLANT, FLOTATION
              CU- 21.  2 6
12.5 YR DEPRECIATION
     ADJUSTED COST (ASARCO)
              JULY 31, 1980

COPPER                    100000.0 TON   PER YEAR
```

```
-----------------------------------------------------------------------
                                                  MMBTU/YR   PERCENT
-----------------------------------------------------------------------
UNIT OPERATION
  CRUSHING     AND STORAGE                           8752.       .13
  NORANDA      SMELTING                             82318.      1.23
  SLAG CRUSH, GRIND, FLOAT                         146394.      2.19
  ANODE        CASTING                             165073.      2.47
  ELECTROLYTIC REFINING                           1685022.     25.19
  GAS COOLING & CLEANING                           101413.      1.52
  ABSORPTION                                       235069.      3.51
  SULFUR   PRECIPITATION                            32973.       .49
  SULFUR       RECOVERY                            119628.      1.79
  H2S          GENERATION                         3674595.     54.92
  SODIUM SULFATE REMOVAL                            79476.      1.19
  OXYGEN PLANT                                     359625.      5.38
-----------------------------------------------------------------------
    TOTAL FOR PLANT                               6690339.    100.00

ENERGY SOURCE
  ELECTRICITY LOW V                                310802.      4.65
  ELECTRICITY INT V                                769219.     11.50
  ELECTRICITY LINE V                               185031.      2.77
  NATURAL GAS                                     4275908.     63.91
  STEAM                                           2433074.     36.37
  STEAM                                          -1475040.    -22.05
  SILICA FLUX                                        1389.       .02
  K AMYL XANTHATE                                    2466.       .04
  MIC                                                3288.       .05
  LEAD ANODE                                         2852.       .04
  GLUE                                                101.       .00
  GOULAC                                             5036.       .08
  H2SO4                                               244.       .00
  LIME                                              90036.      1.35
  CITRIC ACID                                        5625.       .08
  SODA ASH                                          78435.      1.17
  KEROSINE                                           1794.       .03
-----------------------------------------------------------------------
    TOTAL FOR PLANT                               6690339.    100.00

UNIT ENERGY REQUIREMENT       66.9034 MMBTU PER  TON  COPPER
```

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Noranda Process--With Direct Reduction of SO_2 in Gas

In the third variation of the Noranda process, the offgas is treated in an ASARCO sulfur dioxide reduction plant which reduces SO_2 in the gas to elemental sulfur. This modification recovers 81.94 percent of the 457.9 tons per day of sulfur in the feed as elemental sulfur. The balance of the sulfur is distributed as follows, in percent: 0.15 in slag (flotation tailing), 1.81 in fugitive gas leaked within smelter, 4.82 as neutralized acid sludge, and 11.28 vented up the stack (1.64 from anode furnace and 9.64 from SO_2 reduction plant tail gas). A materials balance flowsheet for this process is shown in Figure 4, and costs and energy requirements are presented in Tables 11 through 13.

4. FLASH SMELTING PROCESS

Two types of flash furnaces are used for copper smelting: the Outokumpu furnace developed by Outokumpu Oy in Finland[7-11] and the International Nickel Company (INCO) furnace used at Sudbury, Ontario.[12] In these processes dry flotation concentrates are injected with flux and either preheated air (Outokumpu) or oxygen (INCO) into a combustion chamber maintained at smelting temperature by "flash" combustion of iron and sulfur in the suspended particles. Schematic diagrams in Figure 5 show the similarities and differences in the two processes.

The Outokumpu furnace consists of a "U"-shaped structure built in three sections enclosed in a steel shell: (1) a vertical reaction shaft, (2) a horizontal settler section, and (3) a vertical gas uptake shaft.

[7] "Smelter at Harjavalta" Min. Magazine, May 1973, 6 pp.

[8] Mealey, M. Japan's Tamano Copper Smelter, the Most Modern in the World. Eng. and Min. J., June 1972, pp. 130-131.

[9] Harkki, S. U. and J. T. Juusela. New Development in Outokumpu Flash Smelting Method. Pres. at 103rd Ann. AIME Meeting, Dallas, Tex., February 1974, 20 pp.

[10] Torii, Takashi, Jun Minoura, and Kiyoshi Sato. The Dowa Mining Co., Ltd., Japan. Development and Improvement of the Flash Smelting Furnace Operation at the Kosaka Smelter of the Dowa Mining Co., Ltd. The First Internat. Flash Smelting Cong., Finland, Oct. 23-27, 1972, 18 pp.

[11] Kitamura, T. and T. Shibata. Flash Smelting at Tamano Smelter, Hibi Kyodo Smelting Co. Pres. at the TMS/AIME Ann. Meeting, Chicago, Ill., Feb. 26-Mar. 1, 1973, 13 pp.

[12] Merla, S., C. E. Young, and J. W. Matousek. Recent Developments in the INCO Oxygen Flash Smelting Process. Pres. at 102nd Ann. AIME Meeting in San Francisco, Calif., February 1972. 16 pp.

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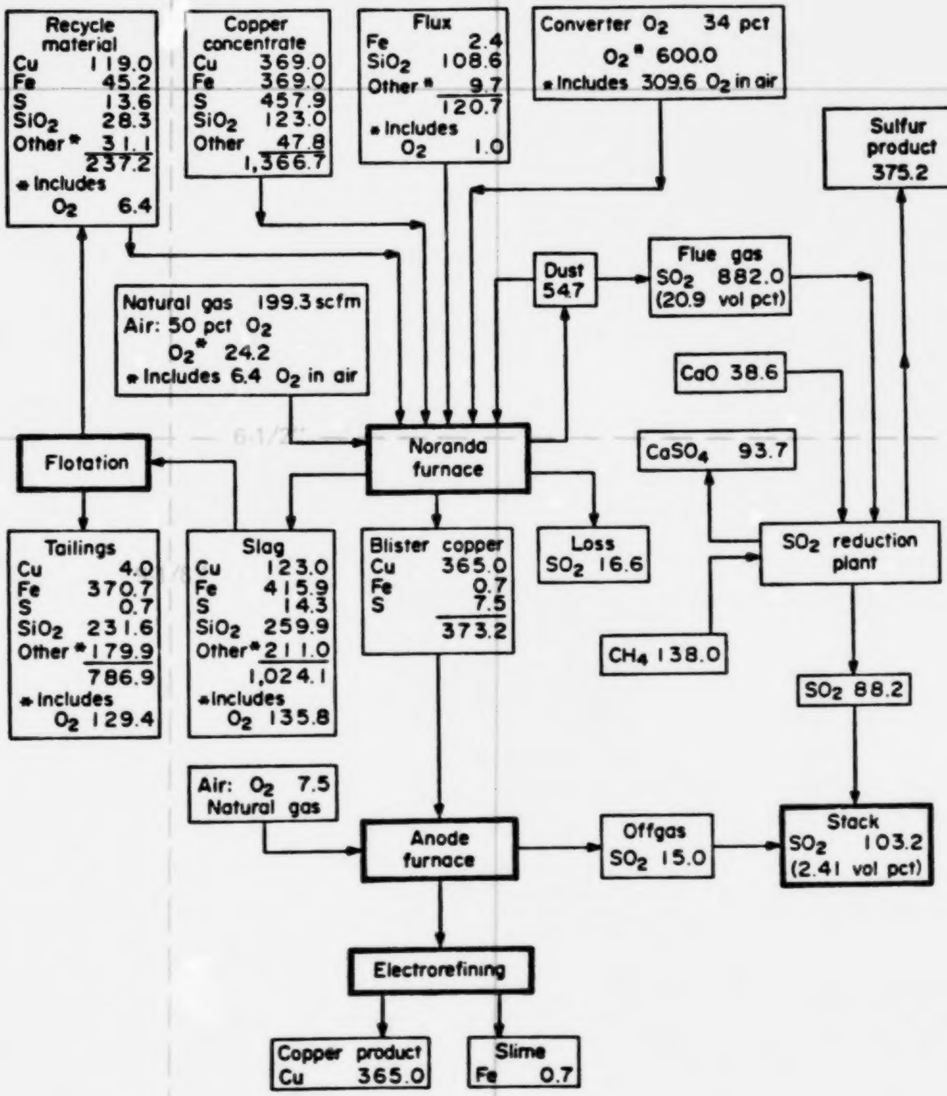
Recycle material
Cu 119.0
Fe 45.2
S 13.6
SiO_2 28.3
Other* 31.1
237.2
*Includes O_2 6.4
Copper concentrate
Cu 369.0
Fe 369.0
S 457.9
SiO_2 123.0
Other 47.8
1,366.7
Flux
Fe 2.4
SiO_2 108.6
Other* 9.7
120.7
*Includes O_2 1.0
Converter O_2 34 pct
O_2* 600.0
*Includes 309.6 O_2 in air
Sulfur product 375.2
Dust 54.7
Flue gas SO_2 882.0 (20.9 vol pct)
Natural gas 199.3 scfm
Air: 50 pct O_2
O_2* 24.2
*Includes 6.4 O_2 in air
CaO 38.6
Flotation
Noranda furnace
$CaSO_4$ 93.7
Tailings
Cu 4.0
Fe 370.7
S 0.7
SiO_2 231.6
Other* 179.9
786.9
*Includes O_2 129.4
Slag
Cu 123.0
Fe 415.9
S 14.3
SiO_2 259.9
Other* 211.0
1,024.1
*Includes O_2 135.8
Blister copper
Cu 365.0
Fe 0.7
S 7.5
373.2
Loss SO_2 16.6
SO_2 reduction plant
CH_4 138.0
SO_2 88.2
Air: O_2 7.5 Natural gas
Anode furnace
Offgas SO_2 15.0
Stack SO_2 103.2 (2.41 vol pct)
Electrorefining
Copper product Cu 365.0
Slime Fe 0.7

FIGURE 4.-Material balance and flow diagram for Noranda process with use of direct reduction of offgas. (tons per day)

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TABLE 11. - Annual operating costs, $, of unit operations for Noranda copper smelter using direct reduction of SO_2

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	PCT
DIRECT COST				
MATERIALS				
SILICA FLUX	33071.8 TON	10.00	330700.	.36
N AMYL XANTHATE	123300.0 LB	1.00	123300.	.13
MIC	164400.0 LB	.39	64100.	.07
LEAD ANODE	105.6 TON	3089.00	326300.	.36
GLUE	5049.8 LB	.90	4500.	.00
GOULAC	251777.8 LB	.15	37800.	.04
H2SO4	294.1 TON	20.00	5900.	.01
LIME	10592.5 TON	53.40	565600.	.62
TOTAL			1458200.	1.59
UTILITIES				
ELECTRICITY	125403.7041 MKWHR	40.00	5016100.	5.48
NATURAL GAS, CONSUMED	7035881.4 MCF	3.15	22163000.	24.21
WATER, PROCESS	335106.8 MGAL	.34	113900.	.12
WATER, COOLING	5307297.7 MGAL	.06	318400.	.35
STEAM	2002996.0 MLB	4.22	8452600.	9.22
CREDIT FOR STEAM	1963348.4 MLB	-4.22	-8285300.	-9.04
TOTAL			27778700.	30.34
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4253200.	4.65
SUPERVISION .150			638000.	.69
TOTAL, D			4891200.	5.34
PLANT MAINTENANCE				
LABOR			4348500.	4.75
SUPERVISION .200			869600.	.95
MATERIALS			6522500.	7.12
TOTAL, M			11740600.	12.82
PAYROLL OVERHEAD .600(PAYROLL)			6065700.	6.63
OPERATING SUPPLIES, S .200(M)			2348200.	2.56
TOTAL DIRECT COST			54282600.	59.29
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			7592000.	8.29
FIXED COST				
TAXES AND INSURANCE .020			5304400.	5.79
DEPRECIATION 12.500 YR			24376000.	26.64
TOTAL			29680400.	32.42
TOTAL ANNUAL OPERATING COST			91555000.	100.00

CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
DIRECT SO2 REDUCTION,FLOTATION
CU- 21. 3 6
REDUCTION OF SO2 WITH NATURAL GAS
SULFUR RECOVERY = 90%

JULY 31, 1980

COPPER 100000.0 TON PER YEAR

ESTIMATE 198.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	122000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	5598000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	15259000.
TOTAL	20979000.

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TABLE 12. - Summary of costs and operating personnel for Noranda copper smelter using direct reduction of SO_2

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	22851100.	5396100.	5.89	.02698
NORANDA SMELTING	34.0	86123100.	19335700.	21.12	.09668
SLAG CRUSH, GRIND, FLOAT	17.0	14953600.	4503100.	4.92	.02252
ANODE CASTING	17.0	15967700.	4505000.	4.92	.02252
ELECTROLYTIC REFINING	106.0	72475200.	25346400.	27.68	.12673
GAS COOLING & CLEANING	2.1	5876600.	1968800.	2.15	.00984
DIRECT SO2 REDUCTION	9.9	19895200.	25999400.	28.40	.13000
OXYGEN PLANT	8.0	11612800.	4500500.	4.92	.02250
TOTAL, T		249755300.			
FACILITIES,.100(T)		24975500.			
UTILITIES,.120(T)		29970200.			
TOTAL FIXED CAPITAL		304701000.			
WORKING CAPITAL		20979000.			
TOTAL CAPITAL	213.0	325680000.	91555000.	100.00	.45777

```
CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
     DIRECT SO2 REDUCTION,FLOTATION
              CU- 21.  3 G
REDUCTION OF SO2 WITH NATURAL GAS
     SULFUR RECOVERY = 90%

              JULY 31, 1980

     14.40974, $/ TON     CU CONCENTRATE
    189.08962, $/ TON     BLISTER CU
     16.04792, $/ TON     SLAG
     44.05575, $/ TON     BLISTER CU
    253.46366, $/ TON     COPPER
       .14434, $/ MSCF    FLUE GAS, 20.9%SO2
       .12645, $/LB       SULFUR
       .02665, $/LB       OXYGEN


COPPER                 100000.0 TON   PER YEAR


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TABLE 13. - Summary of energy requirements for Noranda copper smelter using direct reduction of SO_2

CRUSH, STORE, NORANDA SMELTING, ELECTRO-REF.,
DIRECT SO2 REDUCTION,FLOTATION
CU- 21. 3 G
REDUCTION OF SO2 WITH NATURAL GAS
SULFUR RECOVERY = 90%
JULY 31, 1980

COPPER 100000.0 TON PER YEAR

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8752.	.10
NORANDA SMELTING	82318.	.97
SLAG CRUSH, GRIND, FLOAT	146394.	1.72
ANODE CASTING	165073.	1.94
ELECTROLYTIC REFINING	1733342.	20.36
GAS COOLING & CLEANING	101413.	1.19
DIRECT SO2 REDUCTION	5916620.	69.50
OXYGEN PLANT	359625.	4.22
TOTAL FOR PLANT	8513538.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	163631.	1.92
ELECTRICITY INT V	968077.	11.37
ELECTRICITY LINE V	185031.	2.17
NATURAL GAS	7035881.	82.64
STEAM	2804194.	32.94
STEAM	-2748688.	-32.29
SILICA FLUX	1389.	.02
K AMYL XANTHATE	2466.	.03
MIC	3288.	.04
LEAD ANODE	2852.	.03
GLUE	101.	.00
GOULAC	5036.	.06
H2SO4	244.	.00
LIME	90036.	1.06
TOTAL FOR PLANT	8513538.	100.00

UNIT ENERGY REQUIREMENT 85.1354 MMBTU PER TON COPPER

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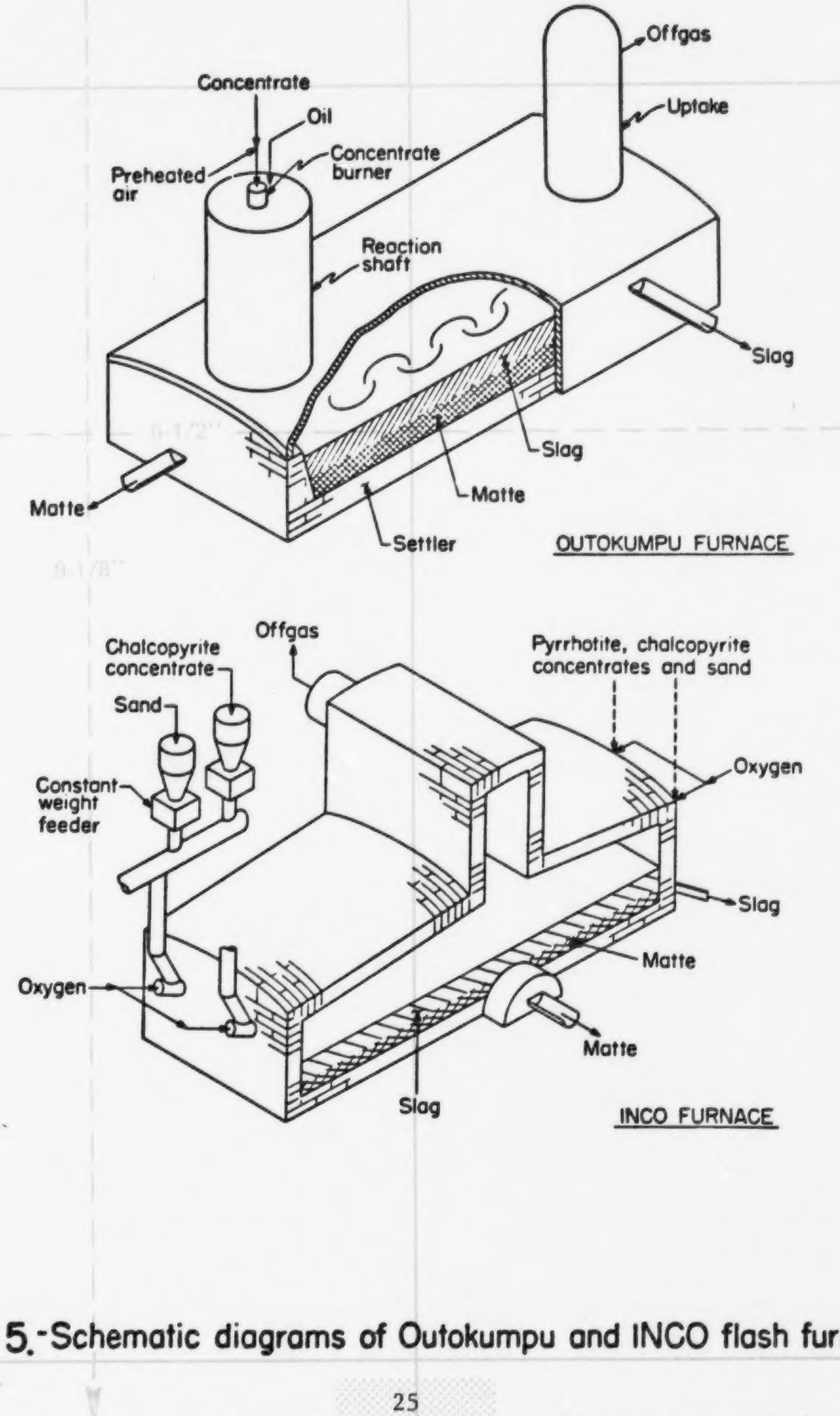
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Uptake
Concentrate
Oil
Preheated air
Concentrate burner
Reaction shaft
Slag
Slag
Matte
Matte
Settler
OUTOKUMPU FURNACE
Chalcopyrite concentrate
Offgas
Pyrrhotite, chalcopyrite concentrates and sand
Sand
Constant-weight feeder
Oxygen
Slag
Matte
Oxygen
Matte
Slag
INCO FURNACE

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FIGURE 5.-Schematic diagrams of Outokumpu and INCO flash furnaces.

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The reaction shaft is a cylindrical combustion chamber lined with chrome-magnesite brick in which the concentrate and air are injected. Excess heat is removed by water-cooled copper rings between the bricks in the lower part of the shaft and by water sprays outside the shaft. Reaction products moving down the reaction shaft impinge onto the surface of the settler section, a rectangular section with a sprung arch roof. A chrome-magnesite lining is used for the walls of the arch, and layers of chrome-magnesite and insulation are used for the base. This section of the furnace has provisions for removing excess heat along the slag line and at hotter sites by water-cooled copper elements. The uptake shaft carries the waste gases to a waste heat boiler. In some operations,[7-9] the uptake shaft serves as a reduction reactor into which additional fuel is injected for reduction of SO_2 to elemental sulfur.

Outokumpu's version of the flash smelter is flexible in that fuel can be burned with the charge to make up for deficiencies in the fuel value of the feed, the grade of the matte can be controlled to yield 40 to 80 percent copper, and a relatively strong SO_2 gas (12 percent) can be produced.

Unlike a reverberatory furnace, there is no recycle of converter slag. Instead, both the flash furnace and converter slags are cooled slowly, crushed, and treated by flotation to make a concentrate containing about 20 percent copper which is blended with feed. Since less iron is recycled and more sulfur can be burned off, a flash furnace can produce a matte richer in copper than a reverberatory furnace. Since the discarded tailings contain part of the minor elements entering the system, the flotation operation helps in reducing the circulating dust load and in preventing a buildup. Copper content of flash furnace slag, about 1.5 percent, is greater than that of a reverberatory furnace, and treatment of the slag by flotation is economically favorable.

In another version of the Outokumpu flash furnace at the Tamano smelter in Japan,[8,11] electrodes are used for additional heating of the settler section to achieve more complete settling. The slags produced are similar in copper content to reverberatory slags, about 0.5 percent, and are discarded.

The INCO oxygen flash furnace differs from the Outokumpu furnace in design. It has a rectangular hearth with a sprung arch roof and a vertical uptake shaft in the center of the roof. The uptake shaft, the roof, and walls are lined with chrome-magnesite brick, and the bottom is covered with magnesite brick. A steel sheet shell covers the entire structure. About 20 percent of the side walls are covered with water-cooled copper jackets in the midfurnace area.

In the INCO furnace, dried concentrate, flux, and pure oxygen are injected horizontally at both ends of the hearth and ignition is spontaneous. Matte and slag settle in the hearth and an offgas goes out the vertical uptake shaft. Since the concentrates are burned in pure oxygen, the offgas contains 80 percent SO_2 which is over six times richer than the Outokumpu flash furnace gas. This also results in higher combustion and slag temperatures which facilitates more complete settling and produces a slag containing 0.6 percent copper that can be discarded. At the INCO plant in Sudbury, Ontario, the feed to the copper smelting operation has a high nickel content which concentrates in the matte. When this matte is converted, a slag is produced containing

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most of the nickel and some copper. This slag is taken to a reverberatory furnace in the nickel smelter. If the INCO furnace were used for smelting regular copper concentrates, as assumed in this report, the slag would be discarded, the matte would be treated in a converter, and the converter slag would be slow cooled, crushed, and floated to make a concentrate that would be blended with the feed.

One of the distinctive characteristics of any flash furnace is the high recirculating dust load due mostly to mechanical carryover by the high velocity of gas through the reactor and partially to condensation of volatile impurities. Recirculation shifts the distribution of impurities and increases their content in the matte and slag. If there should be an undesirable buildup of impurities in the matte, the recirculation of dust can be altered or interrupted to maintain control.[9] This type of control facilitates the disposal of toxic elements in the dust. An Arthur D. Little Study[13] on the establishment of emission standards concluded that until flash smelting technology proves otherwise, the impurity contents of feed should not exceed the known maximum that can be handled by a reverberatory or electric furnace which they designated, in weight-percent, as 0.2 As, 0.1 Sb, 4.5 Pb, and 5.5 Zn. It is not known whether this study has any relevance to the one flash smelter operating in this country.

Some ores with a high lead content can cause excessive buildup of scale. In some of the foreign Outokumpu furnace operations, this problem has already been encountered in the uptake, waste heat boiler, and heat exchanger. Similar problems would be expected for INCO operations with these types of ores. In most cases, such deposits can be removed without shutting down by air lancing, blasting with explosive charges, and shot impingement.

At present only one smelter of the Outokumpu type is operating in the United States. Phelps Dodge has erected a flash smelter that produces 100,000 tons of copper per year. The original plan was to produce 400 tons per day of elemental sulfur from the offgas but the final decision was to make sulfuric acid instead. Outokumpu has sold licenses for the building of over 20 flash smelters for treating copper and nickel concentrates throughout the world. Included in the countries using Outokumpu-type flash smelters are Japan, Australia, Germany, Poland, Rumania, Russia, Spain, India, United States, Mexico, Chile, Zaire, and Botswanda. Only one oxygen flash smelter of the INCO type is in operation at Copper Cliff, Ontario, Canada. Another oxygen flash smelting process, the KIVCET[14] has been developed in the USSR which differs from the INCO process in that it uses a cyclone combustion unit which allegedly increases efficiency through turbulence-induced heat transfer.

[13] Federal Register, Vol. 41, No. 10--Thursday, January 15, 1976, p. 2334.

[14] Melcher, Gerhard, Erich Müller, and Horst Weigel. The KIVCET Cyclone Smelting Process for Impure Copper Concentrates, JOM, July 1976, pp. 4-8.

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Economic evaluations were made of four flash smelters. Two were of the Outokumpu type, one with a sulfuric acid plant, and the other with a Bureau of Mines citrate process plant; two were of the INCO type, one with an acid plant, and the other with a plant for the direct reduction of SO_2.

In the Outokumpu unit, concentrate is fed at a rate of 1,134.8 tons per day (on a dry basis) together with 36.8 tons per day of siliceous flux and 69.1 tons per day of recycle slag concentrate by injection into the furnace with preheated air. The SO_2 concentration in the offgas is 12 percent. These smelters produce 567.9 tons per day of matte containing 54.5 percent copper and 486.2 tons per day of slag containing 1.7 percent copper.

Matte from the Outokumpu flash smelter goes to the converters together with 50.9 tons per day of additional siliceous flux. Production is 304 tons of blister copper per day. Converter and flash smelter gases are combined and treated in an acid plant.

Flash furnace and converter slags, totaling 695.2 tons per day, are combined to form a mixture containing 2.06 percent copper. These combined slags are treated by flotation with recovery of 82.5 percent of the copper as a 17.1-percent concentrate which is recycled. A tailings product of 626.1 tons per day containing 0.4 percent copper is discarded.

Blister copper from the converter containing 99.4 percent copper is sent to an anode furnace and the anodes to the electrolytic cells in the refinery. Electrolytic copper is produced at a rate of 303 tons per day (100,000 tons per 330-day operating year).

Flash Smelter With Preheated Air

Gas to Acid Plant

In this evaluation of an Outokumpu-type flash smelter, the flash furnace offgas, containing 12 percent SO_2, is combined with offgas from a converter, containing 2.5 percent SO_2, and the resulting gas, containing 4.8 percent SO_2, goes to a 1,250-ton-per-day capacity, double-contact acid plant that recovers 1,050.6 tons per day of byproduct acid. This modification recovers 90.31 percent of the 380.2 tons per day of sulfur in the feed as sulfuric acid. The balance of the sulfur is distributed as follows, in percent: 0.68 in slag (flotation tailing), 0.24 in fugitive dust and 3.0 in fugitive gas (both as leakage within the smelter), 4.81 as neutralized acid sludge, and 0.96 vented up the stack. A materials balance flowsheet for this process is shown in Figure 6 and costs and energy requirements are presented in Tables 14 through 16.

Gas to Citrate Process Plant

In this version of an Outokumpu-type smelter, a Bureau of Mines citrate process plant is used to treat the offgas resulting in the recovery of 89.38 percent of the sulfur in the feed, 339.8 tons per day, as elemental sulfur. The balance of the sulfur is distributed as follows, in percent: 0.68 in slag (flotation tailing), 0.24 in fugitive dust and 3.0 in fugitive gas (both as

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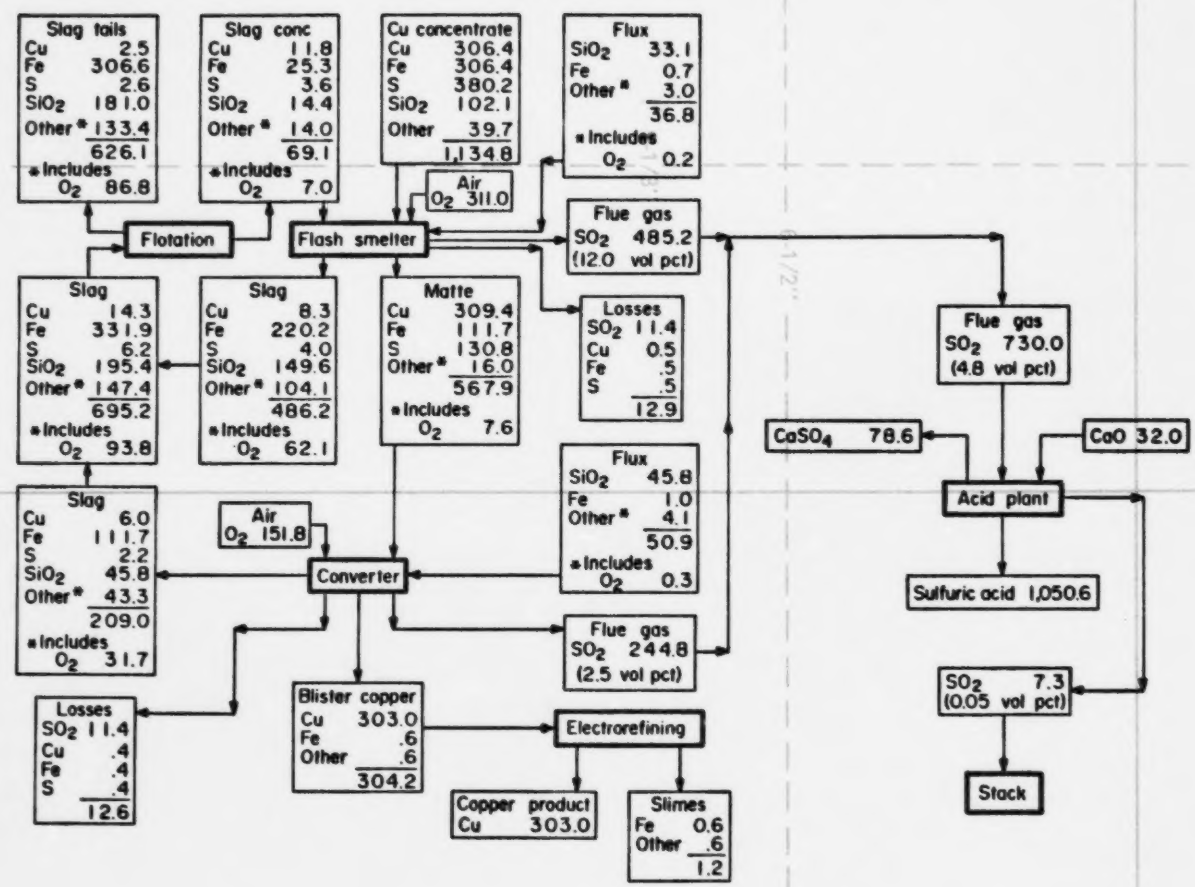
Slag tails
Cu 2.5
Fe 306.6
S 2.6
SiO2 181.0
Other* 133.4
626.1
*Includes O2 86.8
Slag conc
Cu 11.8
Fe 25.3
S 3.6
SiO2 14.4
Other* 14.0
69.1
*Includes O2 7.0
Cu concentrate
Cu 306.4
Fe 306.4
S 380.2
SiO2 102.1
Other 39.7
1,134.8
Flux
SiO2 33.1
Fe 0.7
Other* 3.0
36.8
*Includes O2 0.2
Air O2 311.0
Flotation
Flash smelter
Flue gas
SO2 485.2
(12.0 vol pct)
Slag
Cu 14.3
Fe 331.9
S 6.2
SiO2 195.4
Other* 147.4
695.2
*Includes O2 93.8
Slag
Cu 8.3
Fe 220.2
S 4.0
SiO2 149.6
Other* 104.1
486.2
*Includes O2 62.1
Matte
Cu 309.4
Fe 111.7
S 130.8
Other* 16.0
567.9
*Includes O2 7.6
Losses
SO2 11.4
Cu 0.5
Fe .5
S .5
12.9
Flue gas
SO2 730.0
(4.8 vol pct)
CaSO4 78.6
CaO 32.0
Acid plant
Sulfuric acid 1,050.6
SO2 7.3
(0.05 vol pct)
Stack
Slag
Cu 6.0
Fe 111.7
S 2.2
SiO2 45.8
Other* 43.3
209.0
*Includes O2 31.7
Air O2 151.8
Converter
Flux
SiO2 45.8
Fe 1.0
Other* 4.1
50.9
*Includes O2 0.3
Flue gas
SO2 244.8
(2.5 vol pct)
Losses
SO2 11.4
Cu .4
Fe .4
S .4
12.6
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Copper product
Cu 303.0
Slimes
Fe 0.6
Other .6
1.2

FIGURE 6. - Material balance and flow diagram for flash smelter with an acid plant for flash furnace and converter gases. (tons per day)

TABLE 14. - Annual operating cost, $, of unit operations for a flash copper smelter with an acid plant for flash smelter and converter

	ANNUAL CONSUMPTION	UNIT COST	OPERATING $	COST, PCT
DIRECT COST				
MATERIALS				
SILICA FLUX	28938.7 TON	10.00	289400.	.39
LEAD ANODE	105.6 TON	3089.00	326300.	.44
GLUE	5049.8 LB	.90	4500.	.01
GOULAC	251777.8 LB	.15	37800.	.05
H2SO4	294.1 TON	20.00	5900.	.01
LIME	10556.8 TON	53.40	563700.	.76
K AMYL XANTHATE	99000.0 LB	1.00	99000.	.13
MIC	132000.0 LB	.39	51500.	.07
TOTAL			1378100.	1.86
UTILITIES				
ELECTRICITY	109971.8760 MKWHR	40.00	4398900.	5.93
NATURAL GAS, CONSUMED	1829853.0 MCF	3.15	5764000.	7.78
WATER, PROCESS	110393.6 MGAL	.34	37500.	.05
WATER, COOLING	208022.8 MGAL	.06	12500.	.02
STEAM	1053600.6 MLB	4.22	4446200.	5.99
CREDIT FOR STEAM	1053604.7 MLB	-4.22	-4446200.	-5.99
TOTAL			10212900.	13.78
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4672600.	6.30
SUPERVISION .150			700800.	.95
TOTAL, D			5373400.	7.25
PLANT MAINTENANCE				
LABOR			4295300.	5.79
SUPERVISION .200			859000.	1.16
MATERIALS			6442800.	8.70
TOTAL, M			11597100.	15.65
PAYROLL OVERHEAD .600(PAYROLL)			6316600.	8.52
OPERATING SUPPLIES, S .200(M)			2319400.	3.13
TOTAL DIRECT COST			37197500.	50.18
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			7716000.	10.41
FIXED COST				
TAXES AND INSURANCE .020			5129100.	6.92
DEPRECIATION 12.500 YR			24079400.	32.48
TOTAL			29208500.	39.41
TOTAL ANNUAL OPERATING COST			74122000.	100.00

RAW MAT.PREP,FLASH SMELTING,CONVERTING,ELECTRO-
REF,ACID PLANT,FLOTATION
CU- 16. 1 6
CONTACT ACID PLANT, H2SO4 RECOVERY = 99%
4.8% SO2, 125200 SCFM

JULY 31, 1980

COPPER	100000.0 TON PER YEAR

ESTIMATE 196.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	115000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	4170000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	12354000.
TOTAL	16639000.

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```
RAW MAT.PREP,FLASH SMELTING,CONVERTING,ELECTRO-
     REF,ACID PLANT,FLOTATION
             CU- 16.  1 G
CONTACT ACID PLANT, H2SO4 RECOVERY = 99%
     4.8% SO2, 125200 SCFM

               JULY 31, 1980

       13.08387, $/ TON    CU CONCENTRATE
       80.43990, $/ TON    MATTE
       90.68872, $/ TON    BLISTER CU
       41.03423, $/ TON    BLISTER CU
      266.77227, $/ TON    COPPER
       30.17122, $/ TON    SULFURIC ACID
       16.55447, $/ TON    COPPER SLAG


COPPER                  100000.0 TON   PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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TABLE 15. - Summary of costs and operating personnel for a flash copper smelter with an acid plant for flash smelter and converter

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST,		UNIT PRODUCTION COST,$/LB COPPER
			$	PCT	
CRUSHING AND STORAGE	19.0	20297200.	4899700.	6.61	.02450
FLASH SMELTING	38.0	59900600.	15075000.	20.34	.07537
CONVERTING	25.0	35615100.	9094900.	12.27	.04547
ANODE CASTING	17.0	13778400.	4115200.	5.55	.02058
ELECTROLYTIC REFINING	106.0	73149400.	26677200.	35.99	.13339
CONTACT ACID PLANT	12.0	32190000.	10460500.	14.11	.05230
SLAG CRUSH, GRIND, FLOAT	17.0	11784100.	3799500.	5.13	.01900
TOTAL, T		246714800.			
FACILITIES,.100(T)		24671500.			
UTILITIES,.120(T)		29605700.			
TOTAL FIXED CAPITAL		300992000.			
WORKING CAPITAL		16639000.			
TOTAL CAPITAL	234.0	317631000.	74122000.	100.00	.37061

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TABLE 16. - Summary of energy requirements for a flash smelter with an acid plant for flash smelter and converter

```
                                                    RAW MAT.PREP,FLASH SMELTING,CONVERTING,ELECTRO-
                                                         REF,ACID PLANT,FLOTATION
                                                                CU- 16.  1 6
                                                    CONTACT ACID PLANT, H2SO4 RECOVERY = 99%
                                                          4.0% SO2, 125200 SCFM
                                                                JULY 31, 1980

                                                  COPPER                100000.0 TON   PER YEAR
-----------------------------------------------------------------
                                             MMBTU/YR  PERCENT
-----------------------------------------------------------------
UNIT OPERATION
  CRUSHING     AND STORAGE                      8752.      .28
  FLASH        SMELTING                       374677.    12.13
  CONVERTING                                  175531.     5.68
  ANODE        CASTING                        160624.     5.20
  ELECTROLYTIC REFINING                      1686748.    54.62
  CONTACT ACID PLANT                          564317.    18.27
  SLAG CRUSH, GRIND, FLOAT                    117702.     3.81
-----------------------------------------------------------------
    TOTAL FOR PLANT                          3088352.   100.00

ENERGY SOURCE
  ELECTRICITY LOW V                           235965.     7.64
  ELECTRICITY INT V                           733709.    23.76
  ELECTRICITY LINE V                          185031.     5.99
  NATURAL GAS                                1829853.    59.25
  STEAM                                      1475041.    47.76
  STEAM                                     -1475047.   -47.76
  SILICA FLUX                                   1215.      .04
  LEAD ANODE                                    2852.      .09
  GLUE                                           101.      .00
  GOULAC                                        5036.      .16
  H2SO4                                          244.      .01
  LIME                                         89733.     2.91
  K AMYL XANTHATE                               1980.      .06
  MIC                                           2640.      .09
-----------------------------------------------------------------
    TOTAL FOR PLANT                          3088352.   100.00

UNIT ENERGY REQUIREMENT       30.8835 MMBTU PER  TON  COPPER
```

leakage within the smelter), 4.81 as neutralized acid sludge, 0.93 as Glauber's salt and 0.96 up the stack. A materials balance flowsheet for this process is shown in Figure 7, and costs and energy requirements are presented in Tables 17 through 19.

In the smelting of a copper concentrate with an INCO flash furnace the amount of copper lost in the slag flotation tailings is assumed to be slightly greater than in the Outokumpu operation, and a slightly higher feed rate must be used. Concentrate is injected into the furnace with oxygen at a rate of 1,142.6 tons per day (on a dry basis) together with 36.8 tons per day of siliceous flux and 56.7 tons per day of recycle slag concentrate. The SO_2 concentration in the offgas is 80 percent. For purposes of this evaluation, the smelter is assumed to produce 637.7 tons per day of matte containing 49.4 percent copper and 400.6 tons per day of slag containing 0.62 percent copper.

Matte from the INCO flash furnace goes to the converters together with 75.3 tons per day of additional siliceous flux to produce 304 tons per day of blister copper. Converter gas is cooled by infiltration of air and passed through an electrostatic precipitator before mixing with gas from the flash furnace.

INCO flash furnace slag is discarded, but 315.7 tons per day of converter slag containing 3.73 percent copper are treated by flotation to recover 82.2 percent of the copper as a 17.1 percent concentrate which is recycled. A tailings product of 259.0 tons per day containing 0.81 percent copper is discarded.

Flash Furnace With Oxygen

Gas to Acid Plant

This evaluation covers an INCO-type flash smelter operating as described above. The offgas, which contains 80 percent SO_2, is mixed with converter gas containing 2.5 percent SO_2, and the resulting gas, which contains 4.8 percent SO_2, goes to a 1,250-ton-capacity, double-contact acid plant that recovers 1,054.0 tons of byproduct acid per day. This modification recovers 89.92 percent of the 382.8 tons per day of sulfur in the feed as sulfuric acid. The balance of the sulfur is distributed as follows, in percent: 0.47 in converter slag (flotation tailing), 0.65 in flash furnace slag, 0.24 in fugitive dust and 2.98 in fugitive gas (both as leakage within the smelter), 4.79 as neutralized acid sludge, and 0.95 vented up the stack. A materials balance flowsheet for this process is shown in Figure 8, and costs and energy requirements are presented in Tables 20 through 22.

Direct Reduction of SO_2 in Gas

In this modification of the INCO flash smelter, the offgases are reduced to elemental sulfur with methane (CH_4). Elemental sulfur production is 311.6 tons per day which is 81.31 percent of the sulfur in the feed. The balance of the sulfur, in percent, is distributed as follows: 0.47 in converter slag (flotation tailing), 0.65 in flash furnace slag, 0.24 in fugitive

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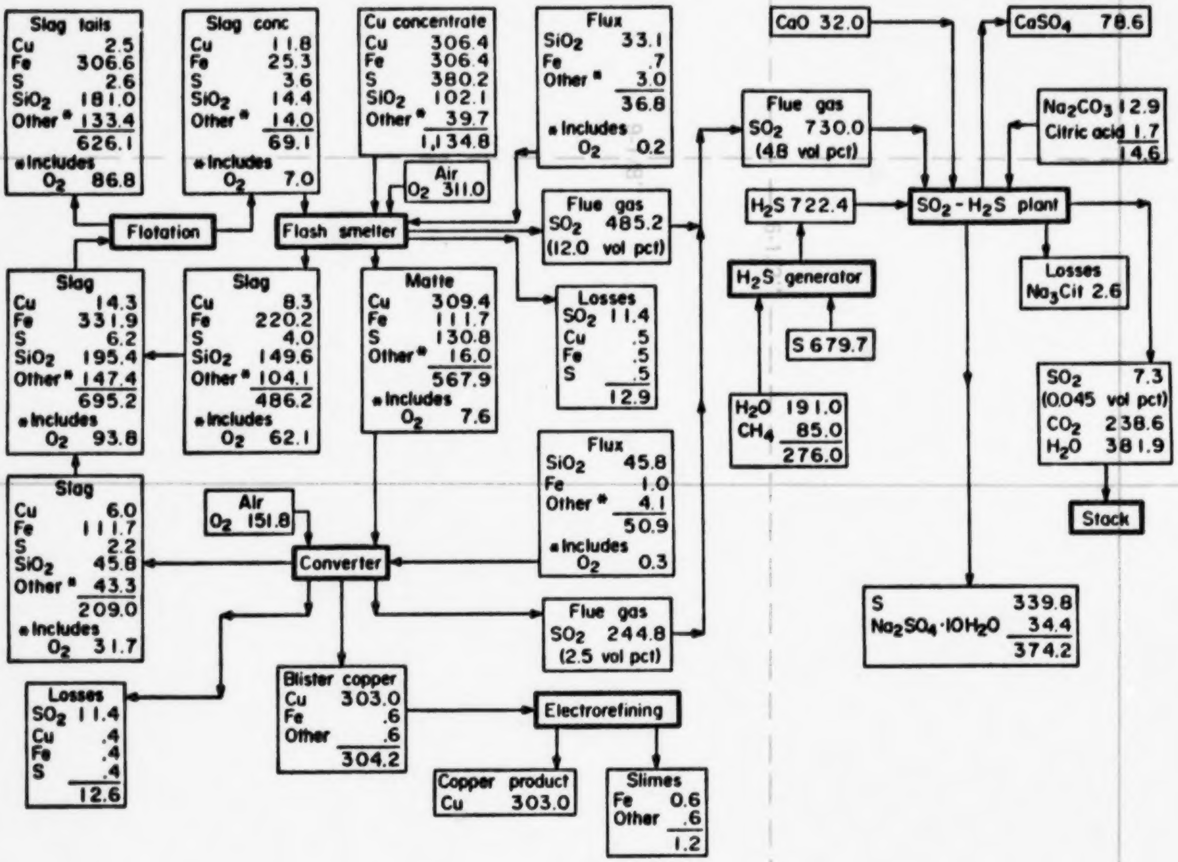
Slag tails
Cu 2.5
Fe 306.6
S 2.6
SiO2 181.0
Other * 133.4
626.1
* Includes O2 86.8
Slag conc
Cu 11.8
Fe 25.3
S 3.6
SiO2 14.4
Other * 14.0
69.1
* Includes O2 7.0
Cu concentrate
Cu 306.4
Fe 306.4
S 380.2
SiO2 102.1
Other * 39.7
1,134.8
Flux
SiO2 33.1
Fe .7
Other * 3.0
36.8
* Includes O2 0.2
Air
O2 311.0
Flotation
Flash smelter
Flue gas
SO2 485.2
(12.0 vol pct)
Slag
Cu 14.3
Fe 331.9
S 6.2
SiO2 195.4
Other * 147.4
695.2
* Includes O2 93.8
Slag
Cu 8.3
Fe 220.2
S 4.0
SiO2 149.6
Other * 104.1
486.2
* Includes O2 62.1
Matte
Cu 309.4
Fe 111.7
S 130.8
Other * 16.0
567.9
* Includes O2 7.6
Losses
SO2 11.4
Cu .5
Fe .5
S .5
12.9
Slag
Cu 6.0
Fe 111.7
S 2.2
SiO2 45.8
Other * 43.3
209.0
* Includes O2 31.7
Air
O2 151.8
Converter
Flux
SiO2 45.8
Fe 1.0
Other * 4.1
50.9
* Includes O2 0.3
Flue gas
SO2 244.8
(2.5 vol pct)
Losses
SO2 11.4
Cu .4
Fe .4
S .4
12.6
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Copper product
Cu 303.0
Slimes
Fe 0.6
Other .6
1.2
CaO 32.0
Flue gas
SO2 730.0
(4.8 vol pct)
H2S 722.4
H2S generator
S 679.7
H2O 191.0
CH4 85.0
276.0
SO2 - H2S plant
CaSO4 78.6
Na2CO3 12.9
Citric acid 1.7
14.6
Losses
Na3Cit 2.6
SO2 7.3
(0.045 vol pct)
CO2 238.6
H2O 381.9
Stack
S 339.8
Na2SO4·10H2O 34.4
374.2

FIGURE 7. - Material balance and flow diagram for flash smelter with a Bureau of Mines citrate process for flash furnace and converter gases. (tons per day)

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TABLE 17. - Annual operating cost, $, of unit operations for a flash copper smelter with Bureau of Mines citrate plant for flash smelter and converter

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	PCT
DIRECT COST				
MATERIALS				
SILICA FLUX	28938.7 TON	10.00	289400.	.31
LEAD ANODE	105.6 TON	3089.00	326300.	.35
GLUE	5049.8 LB	.90	4500.	.00
GOULAC	251777.8 LB	.15	37800.	.04
H2SO4	294.1 TON	20.00	5900.	.01
K AMYL XANTHATE	99000.0 LB	1.00	99000.	.11
MIC	132000.0 LB	.39	51500.	.06
LIME	10556.8 TON	53.40	563700.	.61
CITRIC ACID	560.2 TON	1360.00	761900.	.82
SODA ASH	4250.0 TON	60.00	255000.	.27
KEROSINE	851221.7 GAL	.95	808700.	.86
TOTAL			3203700.	3.44
UTILITIES				
ELECTRICITY	89935.4600 MKWHR	40.00	3597400.	3.87
NATURAL GAS, CONSUMED	5709624.2 MCF	3.15	17985300.	19.32
WATER, PROCESS	86124.3 MGAL	.34	29300.	.03
WATER, COOLING	7108162.2 MGAL	.06	426500.	.46
STEAM	1723291.5 MLB	4.22	7272400.	7.82
CREDIT FOR STEAM	1759589.8 MLB	-4.22	-7425500.	-7.97
TOTAL			21885400.	23.53
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4772400.	5.13
SUPERVISION .150			715900.	.77
TOTAL, D			5488300.	5.90
PLANT MAINTENANCE				
LABOR			4712400.	5.07
SUPERVISION .200			942300.	1.01
MATERIALS			7068600.	7.60
TOTAL, M			12723300.	13.68
PAYROLL OVERHEAD .600(PAYROLL)			6685700.	7.19
OPERATING SUPPLIES, S .200(M)			2544600.	2.74
TOTAL DIRECT COST			52531000.	56.47
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			8302500.	8.93
FIXED COST				
TAXES AND INSURANCE .020			5751900.	6.18
DEPRECIATION 12.500 YR			26436600.	28.41
TOTAL			32188500.	34.60
TOTAL ANNUAL OPERATING COST			93022000.	100.00

UPDATED CITRATE PLANT, REVISED COST (ASARCO)
KEROSENE FLOTATION
CU- 16. 2 G
RAW MAT.PREP,FLASH SMELTING,CONVERTING,ELECTRO-REF,FLOTATION,CITRATE PROCESS

JULY 31, 1980

COPPER 100000.0 TON PER YEAR

ESTIMATE 215.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	267000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	5549000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	15504000.
TOTAL	21320000.

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TABLE 18. - Summary of costs and operating personnel for a flash copper smelter with Bureau of Mines citrate plant for flash smelter and converter

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20297200.	4897900.	5.27	.02449
FLASH SMELTING	38.0	59900600.	14945100.	16.07	.07473
CONVERTING	25.0	35615100.	9032300.	9.71	.04516
ANODE CASTING	17.0	13778400.	4060200.	4.36	.02030
ELECTROLYTIC REFINING	106.0	73523700.	25600800.	27.52	.12800
SLAG CRUSH, GRIND, FLOAT	17.0	11784100.	3740300.	4.02	.01870
GAS COOLING & CLEANING	2.1	12256900.	3763800.	4.05	.01882
ABSORPTION	2.1	2113400.	2172200.	2.34	.01086
SULFUR PRECIPITATION	4.2	1300000.	588100.	.63	.00294
SULFUR RECOVERY	2.1	10070800.	3340800.	3.59	.01670
H2S GENERATION	4.3	27273900.	19844200.	21.33	.09922
SODIUM SULFATE REMOVAL	2.2	2988200.	1036300.	1.11	.00518
TOTAL, T		270902300.			
INITIAL REAGENTS, IR = 202900.					
FACILITIES,.100(T-IR)		27069900.			
UTILITIES,.120(T-IR)		32483800.			
TOTAL FIXED CAPITAL		330456000.			
WORKING CAPITAL		21320000.			
TOTAL CAPITAL	239.0	351776000.	93022000.	100.00	.46511

```
UPDATED CITRATE PLANT, REVISED COST (ASARCO)
     KEROSENE FLOTATION
            CU- 16.  2 6
RAW MAT.PREP,FLASH SMELTING,CONVERTING,ELECTRO-
     REF,FLOTATION,CITRATE PROCESS

               JULY 31, 1980

      13.07906, $/ TON     CU CONCENTRATE
      79.74675, $/ TON     MATTE
      90.06451, $/ TON     BLISTER CU
      40.48581, $/ TON     BLISTER CU
     256.00826, $/ TON     COPPER
      16.29654, $/ TON     COPPER SLAG
        .10292, $/ MSCF    FLUE GAS, 8.7% SO2
      18.01479, $/ TON     SULFUR
       4.87731, $/ TON     SULFUR
      27.70639, $/ TON     SULFUR
      83.24292, $/ TON     H2S
      90.03937, $/ TON     GLAUBER SALT




COPPER                100000.0 TON   PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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TABLE 19. - Summary of energy requirements for flash copper smelter with a Bureau of Mines citrate plant for flash smelter and converter

```
                                                       UPDATED CITRATE PLANT, REVISED COST (ASARCO)
                                                            KEROSENE FLOTATION
                                                                  CU- 16.  2 6
                                                       RAW MAT.PREP,FLASH SMELTING,CONVERTING,ELECTRO-
                                                            REF,FLOTATION,CITRATE PROCESS
                                                                  JULY 31, 1980

                                                       COPPER                   100000.0 TON   PER YEAR

-----------------------------------------------------------------------
                                              MMBTU/YR   PERCENT
-----------------------------------------------------------------------
UNIT OPERATION
  CRUSHING     AND STORAGE                        8752.       .13
  FLASH        SMELTING                         374677.      5.50
  CONVERTING                                    175531.      2.58
  ANODE        CASTING                          160624.      2.36
  ELECTROLYTIC REFINING                        1634505.     24.01
  SLAG CRUSH, GRIND, FLOAT                      117702.      1.73
  GAS COOLING & CLEANING                        139050.      2.04
  ABSORPTION                                    272599.      4.00
  SULFUR   PRECIPITATION                         31515.       .46
  SULFUR       RECOVERY                         149960.      2.20
  H2S          GENERATION                      3663432.     53.82
  SODIUM SULFATE REMOVAL                         78812.      1.16
-----------------------------------------------------------------------
    TOTAL FOR PLANT                            6807160.    100.00

ENERGY SOURCE
  ELECTRICITY LOW V                             402950.      5.92
  ELECTRICITY INT V                             356342.      5.23
  ELECTRICITY LINE V                            185031.      2.72
  NATURAL GAS                                  5709624.     83.88
  STEAM                                        2412608.     35.44
  STEAM                                       -2463426.    -36.19
  SILICA FLUX                                     1215.       .02
  LEAD ANODE                                      2852.       .04
  GLUE                                             101.       .00
  GOULAC                                          5036.       .07
  H2SO4                                            244.       .00
  K AMYL XANTHATE                                 1980.       .03
  MIC                                             2640.       .04
  LIME                                           89733.      1.32
  CITRIC ACID                                     5602.       .08
  SODA ASH                                       77775.      1.14
  KEROSINE                                       16854.       .25
-----------------------------------------------------------------------
    TOTAL FOR PLANT                            6807160.    100.00

UNIT ENERGY REQUIREMENT        68.0714 MMBTU PER  TON  COPPER
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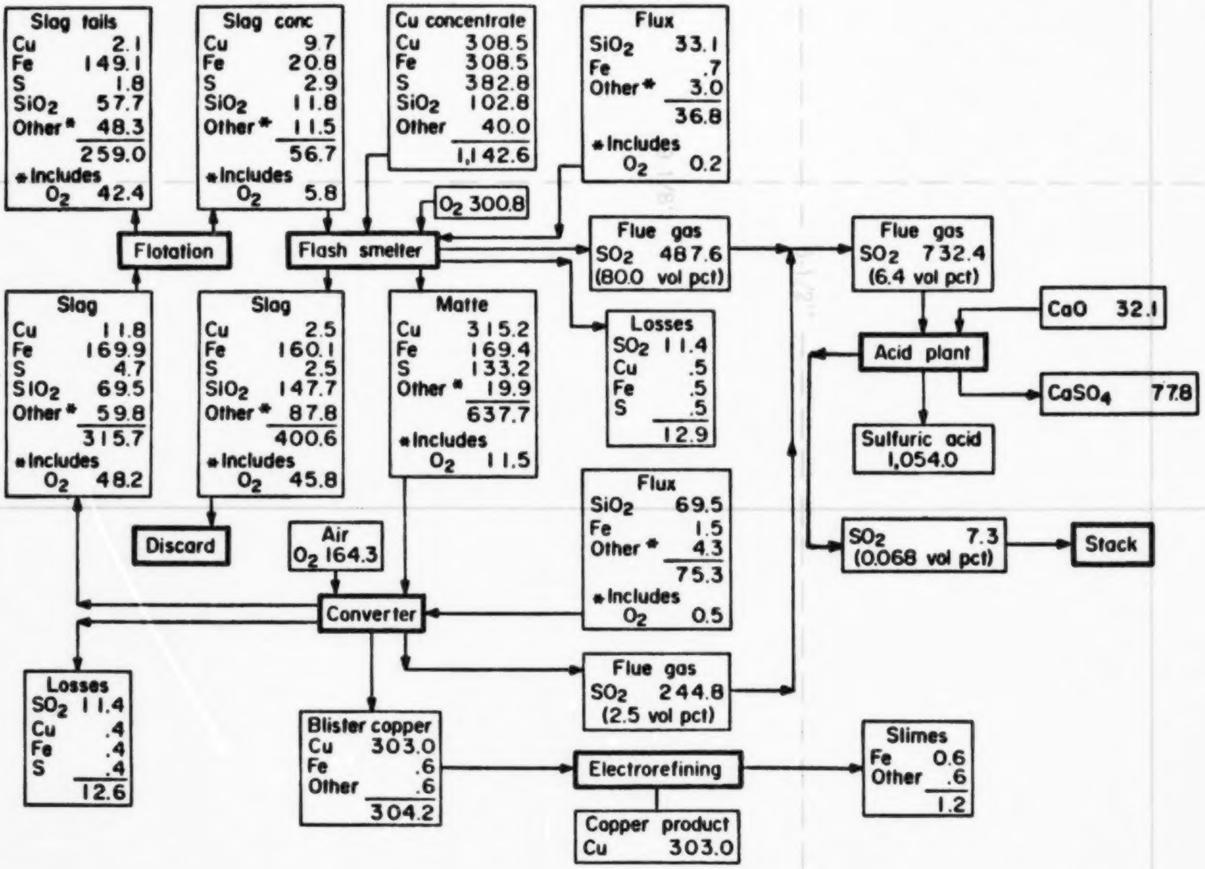
Slag tails
Cu 2.1
Fe 149.1
S 1.8
SiO_2 57.7
Other* 48.3
259.0
*Includes O_2 42.4
Slag conc
Cu 9.7
Fe 20.8
S 2.9
SiO_2 11.8
Other* 11.5
56.7
*Includes O_2 5.8
Cu concentrate
Cu 308.5
Fe 308.5
S 382.8
SiO_2 102.8
Other 40.0
1,142.6
Flux
SiO_2 33.1
Fe .7
Other* 3.0
36.8
*Includes O_2 0.2
O_2 300.8
Flotation
Flash smelter
Flue gas
SO_2 487.6
(80.0 vol pct)
Flue gas
SO_2 732.4
(6.4 vol pct)
CaO 32.1
Acid plant
$CaSO_4$ 77.8
Sulfuric acid
1,054.0
Slag
Cu 11.8
Fe 169.9
S 4.7
SiO_2 69.5
Other* 59.8
315.7
*Includes O_2 48.2
Slag
Cu 2.5
Fe 160.1
S 2.5
SiO_2 147.7
Other* 87.8
400.6
*Includes O_2 45.8
Matte
Cu 315.2
Fe 169.4
S 133.2
Other* 19.9
637.7
*Includes O_2 11.5
Losses
SO_2 11.4
Cu .5
Fe .5
S .5
12.9
Discard
Air
O_2 164.3
Flux
SiO_2 69.5
Fe 1.5
Other* 4.3
75.3
*Includes O_2 0.5
SO_2 7.3
(0.068 vol pct)
Stack
Converter
Losses
SO_2 11.4
Cu .4
Fe .4
S .4
12.6
Flue gas
SO_2 244.8
(2.5 vol pct)
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Copper product
Cu 303.0
Slimes
Fe 0.6
Other .6
1.2

FIGURE 8. - Material balance and flow diagram for oxygen flash smelter with an acid plant for flash furnace and converter gases. (ton per day)

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TABLE 20. - Annual operating cost, $, of unit operations for an oxygen flash copper smelter with an acid plant for flash smelter and converter

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	OPERATING COST, PCT
DIRECT COST				
MATERIALS				
SILICA FLUX	30431.2 TON	10.00	304400.	.42
LEAD ANODE	105.6 TON	3089.00	326300.	.45
GLUE	5049.8 LB	.90	4500.	.01
GOULAC	251777.8 LB	.15	37800.	.05
H2SO4	294.1 TON	20.00	5900.	.01
LIME	10593.1 TON	53.40	565700.	.76
K AMYL XANTHATE	49500.0 LB	1.00	49500.	.07
MIC	66000.0 LB	.39	25700.	.04
TOTAL			1319800.	1.81
UTILITIES				
ELECTRICITY	136013.2715 MKWHR	40.00	5440500.	7.46
NATURAL GAS, CONSUMED	1788699.0 MCF	3.15	5634400.	7.73
WATER, PROCESS	110488.7 MGAL	.34	37600.	.05
WATER, COOLING	1056716.7 MGAL	.06	63400.	.09
STEAM	1053600.6 MLB	4.22	4446200.	6.09
CREDIT FOR STEAM	1053600.6 MLB	-4.22	-4446200.	-6.09
TOTAL			11175900.	15.33
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4832300.	6.63
SUPERVISION .150			724800.	.99
TOTAL, D			5557100.	7.62
PLANT MAINTENANCE				
LABOR			4082700.	5.60
SUPERVISION .200			816500.	1.12
MATERIALS			6124000.	8.40
TOTAL, M			11023200.	15.12
PAYROLL OVERHEAD .600(PAYROLL)			6273800.	8.61
OPERATING SUPPLIES, S .200(M)			2204600.	3.02
TOTAL DIRECT COST			37554400.	51.52
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			7514000.	10.31
FIXED COST				
TAXES AND INSURANCE .020			4935700.	6.77
DEPRECIATION 12.500 YR			22886900.	31.41
TOTAL			27822600.	38.17
TOTAL ANNUAL OPERATING COST			72891000.	100.00

RAW MAT.PREP,O2 FLASH SMELT,CONVERT,ELECTROREF,
FLOAT,CONTACT ACID PLANT
CU- 16. 5 6
CONTACT ACID PLANT, H2SO4 RECOVERY = 99%
6.4 % SO2, 94130 SCFM

JULY 31, 1980

COPPER 100000.0 TON PER YEAR

ESTIMATE 186.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	110000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	4167000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	12149000.
TOTAL	16426000.

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TABLE 21. - Summary of costs and operating personnel for an oxygen flash copper smelter with an acid plant for flash smelter and converter

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20384200.	4910500.	6.74	.02455
FLASH SMELTING	38.0	45298200.	11739200.	16.11	.05870
CONVERTING	25.0	35615100.	9037000.	12.40	.04518
ANODE CASTING	17.0	13778400.	4082300.	5.60	.02041
ELECTROLYTIC REFINING	106.0	73336600.	26155200.	35.88	.13078
CONTACT ACID PLANT	12.0	27258200.	8788000.	12.06	.04394
SLAG CRUSH, GRIND, FLOAT	17.0	7984300.	2737000.	3.75	.01368
OXYGEN PLANT	8.0	10841600.	5441800.	7.47	.02721
TOTAL, T		234496600.			
FACILITIES,.100(T)		23449700.			
UTILITIES,.120(T)		28139700.			
TOTAL FIXED CAPITAL		286086000.			
WORKING CAPITAL		16426000.			
TOTAL CAPITAL	242.0	302512000.	72891000.	100.00	.36445

```
RAW MAT.PREP,O2 FLASH SMELT,CONVERT,ELECTROREF,
     FLOAT,CONTACT ACID PLANT
              CU- 16.  5 6
CONTACT ACID PLANT, H2SO4 RECOVERY = 99%
     6.4 % SO2, 94130 SCFM

                JULY 31, 1980

       13.02320, $/ TON    CU CONCENTRATE
       55.78381, $/ TON    MATTE
       90.11138, $/ TON    BLISTER CU
       40.70617, $/ TON    BLISTER CU
      261.55226, $/ TON    COPPER
       25.26546, $/ TON    H2SO4
       26.23834, $/ TON    COPPER SLAG
         .02998, $/LB      OXYGEN



COPPER                   100000.0 TON   PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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EPA-287 (Cin.)
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TABLE 22. - Summary of energy requirements for an oxygen flash copper smelter with an acid plant for flash smelter and converter

RAW MAT.PREP,O2 FLASH SMELT,CONVERT,ELECTROREF,
FLOAT,CONTACT ACID PLANT
CU- 16. 5 G
CONTACT ACID PLANT, H2SO4 RECOVERY = 99%
6.4 % SO2, 94130 SCFM
JULY 31, 1980

COPPER 100000.0 TON PER YEAR

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8813.	.27
FLASH SMELTING	290241.	8.75
CONVERTING	175531.	5.29
ANODE CASTING	160624.	4.84
ELECTROLYTIC REFINING	1663102.	50.11
CONTACT ACID PLANT	566158.	17.06
SLAG CRUSH, GRIND, FLOAT	67764.	2.04
OXYGEN PLANT	386468.	11.65
TOTAL FOR PLANT	3318700.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	187263.	5.64
ELECTRICITY INT V	1055845.	31.82
ELECTRICITY LINE V	185031.	5.58
NATURAL GAS	1788699.	53.90
STEAM	1475041.	44.45
STEAM	-1475041.	-44.45
SILICA FLUX	1278.	.04
LEAD ANODE	2852.	.09
GLUE	101.	.00
GOULAC	5036.	.15
H2SO4	244.	.01
LIME	90042.	2.71
K AMYL XANTHATE	990.	.03
MIC	1320.	.04
TOTAL FOR PLANT	3318700.	100.00

UNIT ENERGY REQUIREMENT 33.1870 MMBTU PER TON COPPER

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dust and 2.98 in fugitive gas (both as leakage within the smelter), 4.79 as neutralized acid sludge, and 9.56 vented up the stack. A materials balance flowsheet for this process is shown in Figure 9, and costs and energy requirements are presented in Tables 23 through 25.

5. ELECTRIC FURNACE SMELTING

Smelting of concentrates in an electric furnace[15-17] has been recognized as a process that can handle feed materials with a wide range of composition, even preroasted materials, and yield an offgas rich enough in SO_2 (5 to 6 percent) for the production of sulfuric acid.

Most of the electric furnaces used by copper smelters are similar in design, rectangular in shape with arched tops and bottoms and an in-line arrangement of electrodes. The electrodes, which are self-baking, are submerged in the slag, and heating is mainly by resistance rather than arcing. Feed is conveyed along the length of the furnace and introduced around both sides of each of the electrodes. Matte is tapped near the bottom of one of the ends and converter slag is poured into the furnace at the same end. Waste slag is tapped at the opposite end of the furnace.

The furnace feed must be dry and is usually treated in a drying kiln or preroasted. Offgassing around the electrodes is not severe, and a fine feed may be used without excessive carryover of concentrate. Sulfur vapor is the principal gaseous product of the smelting reaction; it burns as it evolves and the composition of sulfur dioxide produced is relatively constant. Enough air is introduced to supply the oxygen required to form the sulfur oxide. This results in low volumes and high SO_2 concentration.

Since gases from converters and preroasters can also be used in the acid plant, virtually all of the minor impurities should be either captured in the gas cleaning system or trapped in the slag. Composition of matte and slag are about the same as that produced by a conventional reverberatory furnace, but because of the lower volume of sweeping gas, more of the trace impurities will remain in the matte and will have to be removed in the converting operation.

[15] Birger, Ydstie. The Electric Copper Matte Furnace--Energy and Material Balances in the System Roaster-Smelter-Converter. Effect on Gas Balance and Acid Plant Economy. Paper pres. at the 104th Ann. AIME Meeting, New York City, Feb. 16-20, 1975.

[16] Dayton, Stanley. Inspiration's Design for Clean Air. Eng. and Min. J., June 1974, pp. 85-96.

[17] Cole, R. C. Inspiration's $54 Million Air Pollution Control Project is Now in Operation. Pay Dirt, Bisbee, Ariz., May 27, 1974.

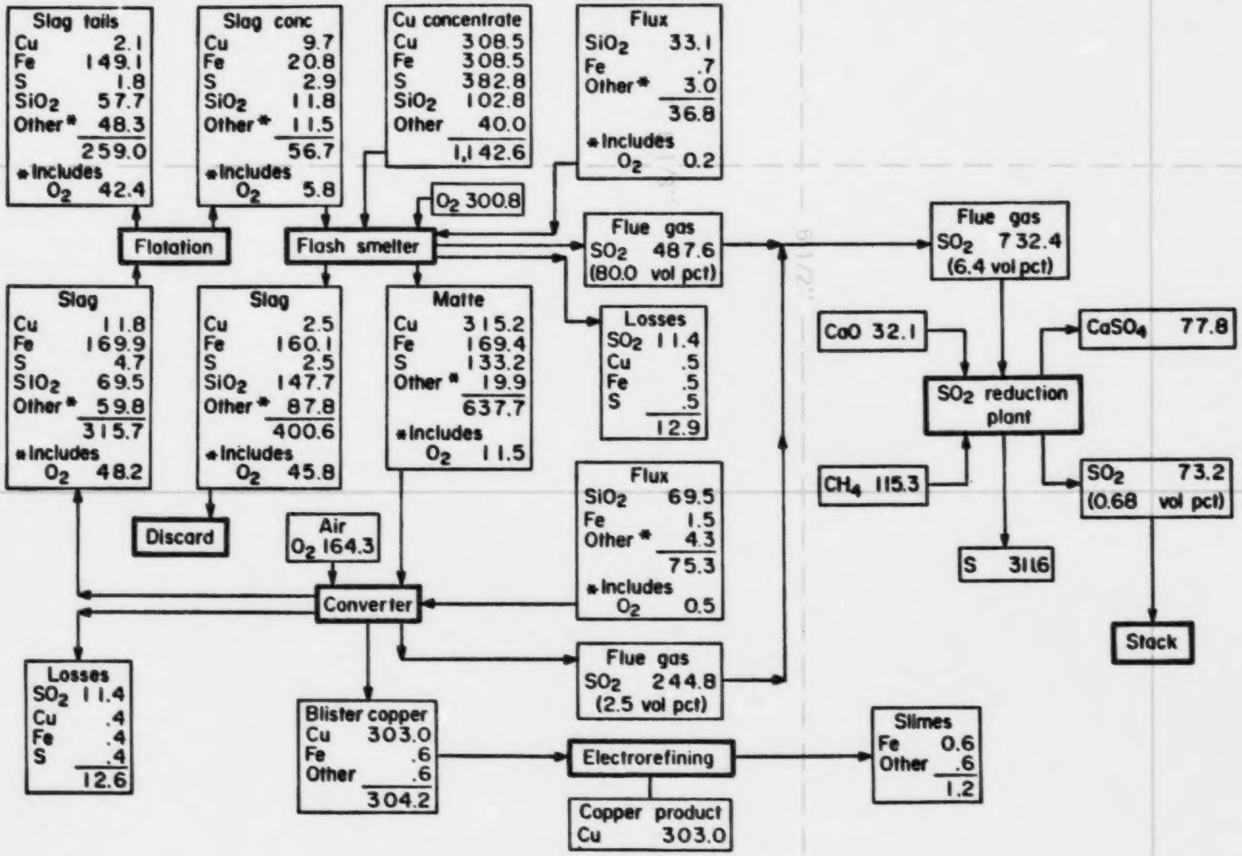
Slag tails
Cu 2.1
Fe 149.1
S 1.8
SiO_2 57.7
Other* 48.3
259.0
*Includes
O_2 42.4
Slag conc
Cu 9.7
Fe 20.8
S 2.9
SiO_2 11.8
Other* 11.5
56.7
*Includes
O_2 5.8
Cu concentrate
Cu 308.5
Fe 308.5
S 382.8
SiO_2 102.8
Other 40.0
1,142.6
Flux
SiO_2 33.1
Fe .7
Other* 3.0
36.8
*Includes
O_2 0.2
O_2 300.8
Flotation
Flash smelter
Flue gas
SO_2 487.6
(80.0 vol pct)
Flue gas
SO_2 732.4
(6.4 vol pct)
Slag
Cu 11.8
Fe 169.9
S 4.7
SiO_2 69.5
Other* 59.8
315.7
*Includes
O_2 48.2
Slag
Cu 2.5
Fe 160.1
S 2.5
SiO_2 147.7
Other* 87.8
400.6
*Includes
O_2 45.8
Matte
Cu 315.2
Fe 169.4
S 133.2
Other* 19.9
637.7
*Includes
O_2 11.5
Losses
SO_2 11.4
Cu .5
Fe .5
S .5
12.9
CaO 32.1
SO_2 reduction plant
$CaSO_4$ 77.8
CH_4 115.3
SO_2 73.2
(0.68 vol pct)
S 311.6
Stack
Discard
Air
O_2 164.3
Converter
Flux
SiO_2 69.5
Fe 1.5
Other* 4.3
75.3
*Includes
O_2 0.5
Flue gas
SO_2 244.8
(2.5 vol pct)
Losses
SO_2 11.4
Cu .4
Fe .4
S .4
12.6
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Copper product
Cu 303.0
Slimes
Fe 0.6
Other .6
1.2

FIGURE 9. - Material balance and flow diagram for oxygen flash smelter with use of direct reduction of flash furnace and converter gases. (tons per day)

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TABLE 23. - Annual operating cost, $, of unit operations for an oxygen flash copper smelter using direct reduction of SO_2 from flash smelter and converter

```
-----------------------------------------------------------------------------
                                    ANNUAL          UNIT      OPERATING COST,
                                  CONSUMPTION       COST           $      PCT
-----------------------------------------------------------------------------
DIRECT COST
  MATERIALS
    SILICA FLUX                     30431.2 TON     10.00      304400.    .32
    LEAD ANODE                        105.6 TON   3089.00      326300.    .34
    GLUE                             5049.8 LB        .90        4500.    .00
    GOULAC                         251777.8 LB        .15       37800.    .04
    H2SO4                             294.1 TON     20.00        5900.    .01
    K AMYL XANTHATE                 49500.0 LB       1.00       49500.    .05
    MIC                             66000.0 LB        .39       25700.    .03
    LIME                            10593.1 TON     53.40      565700.    .58
                                                          ------------ ------
        TOTAL                                                 1319800.   1.37
  UTILITIES                                               ============ ======
    ELECTRICITY                 173487.1914 MKWHR   40.00     6939500.   7.22
    NATURAL GAS, CONSUMED         7063006.8 MCF      3.15    22248500.  23.16
    WATER, PROCESS                 335001.2 MGAL      .34      113900.    .12
    WATER, COOLING                6067930.7 MGAL      .06      364100.    .38
    STEAM                         1692545.7 MLB      4.22     7142500.   7.42
    CREDIT FOR STEAM              1635070.1 MLB     -4.22    -6900000.  -7.17
                                                          ------------ ------
        TOTAL                                                29908500.  31.13
  DIRECT LABOR                                            ============ ======
    LABOR   9.600/MAN HOUR                                    4832300.   5.03
    SUPERVISION   .150                                         724900.    .75
                                                          ------------ ------
        TOTAL, D                                              5557200.   5.78
  PLANT MAINTENANCE                                       ============ ======
    LABOR                                                     4446400.   4.63
    SUPERVISION   .200                                         889300.    .93
    MATERIALS                                                 6669700.   6.94
                                                          ------------ ------
        TOTAL, M                                             12005400.  12.50
  PAYROLL OVERHEAD   .600(PAYROLL)                            6535800.   6.80
  OPERATING SUPPLIES, S   .200(M)                             2401000.   2.50
                                                          ============ ======
        TOTAL DIRECT COST                                    57727700.  60.08
INDIRECT COST
  ADMINISTRATION AND OVERHEAD   .400(D+M+S)                   7985400.   8.31
FIXED COST                                                ============ ======
  TAXES AND INSURANCE   .020                                  5423600.   5.65
  DEPRECIATION 12.500 YR                                     24928300.  25.96
                                                          ------------ ------
        TOTAL                                                30351900.  31.60
                                                          ============ ======
        TOTAL ANNUAL OPERATING COST                          96065000. 100.00
```

```
RAW MAT.PREP,O2 FLASH SMELT,CONVERT,ELECTROREF,
     FLOAT,DIRECT SO2 REDUCTION
              CU- 16.  4 6
REDUCTION OF SO2 WITH NATURAL GAS
     SULFUR RECOVERY = 90%

              JULY 31, 1980



COPPER                    100000.0 TON   PER YEAR


ESTIMATE  202.0 MAINT. MEN,  10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH


              WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS =
  (TOTAL ANNUAL MATERIAL COST)/12          110000.
1 MONTH'S OUT-OF-POCKET EXPENSE =
  (TOTAL AN OP COST-DEPRECIATION)/12      5928000.
2 MONTH'S PRODUCT INVENTORY =
  (TOTAL ANNUAL OPERATING COST)/6        16011000.
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    TOTAL                                22049000.
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TABLE 24. - Summary of costs and operating personnel for an oxygen flash smelter using direct reduction of SO_2 from flash smelter and converter

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20384200.	4911800.	5.11	.02456
FLASH SMELTING	38.0	45298200.	11713400.	12.19	.05857
CONVERTING	25.0	35615100.	9005200.	9.37	.04503
ANODE CASTING	17.0	13778400.	4056700.	4.22	.02028
ELECTROLYTIC REFINING	106.0	72475200.	25357900.	26.40	.12679
SLAG CRUSH, GRIND, FLOAT	17.0	7984300.	2721100.	2.83	.01361
GAS COOLING & CLEANING	2.1	9114200.	3021600.	3.15	.01511
DIRECT SO2 REDUCTION	9.9	39922900.	30852600.	32.12	.15426
OXYGEN PLANT	8.0	10841600.	4424700.	4.61	.02212
TOTAL, T		255414100.			
FACILITIES,.100(T)		25541400.			
UTILITIES,.120(T)		30649500.			
TOTAL FIXED CAPITAL		311605000.			
WORKING CAPITAL		22049000.			
TOTAL CAPITAL	242.0	333654000.	96065000.	100.00	.48032

RAW MAT.PREP,O2 FLASH SMELT,CONVERT,ELECTROREF,
FLOAT,DIRECT SO2 REDUCTION
CU- 16. 4 6
REDUCTION OF SO2 WITH NATURAL GAS
SULFUR RECOVERY = 90%

JULY 31, 1980

13.02664, $/ TON	CU CONCENTRATE
55.66121, $/ TON	MATTE
89.79429, $/ TON	BLISTER CU
40.45091, $/ TON	BLISTER CU
253.57925, $/ TON	COPPER
26.08591, $/ TON	COPPER SLAG
.11486, $/ MSCF	FLUE GAS,10.88%SO2
300.02159, $/ TON	SULFUR
48.75702, $/ TON	OXYGEN

COPPER 100000.0 TON PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

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TABLE 25. - Summary of energy requirements for an oxygen flash copper smelter using direct reduction of SO_2 from flash smelter and converter

RAW MAT.PREP,O2 FLASH SMELT,CONVERT,ELECTROREF,
FLOAT,DIRECT SO2 REDUCTION
CU- 16. 4 G
REDUCTION OF SO2 WITH NATURAL GAS
SULFUR RECOVERY = 90%
JULY 31, 1980

COPPER 100000.0 TON PER YEAR

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8813.	.10
FLASH SMELTING	290241.	3.20
CONVERTING	175531.	1.94
ANODE CASTING	160624.	1.77
ELECTROLYTIC REFINING	1733342.	19.12
SLAG CRUSH, GRIND, FLOAT	67764.	.75
GAS COOLING & CLEANING	133356.	1.47
DIRECT SO2 REDUCTION	6110811.	67.40
OXYGEN PLANT	386460.	4.26
TOTAL FOR PLANT	9066950.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	187263.	2.07
ELECTRICITY INT V	1449322.	15.98
ELECTRICITY LINE V	185031.	2.04
NATURAL GAS	7063007.	77.90
STEAM	2369564.	26.13
STEAM	-2289098.	-25.25
SILICA FLUX	1278.	.01
LEAD ANODE	2852.	.03
GLUE	101.	.00
GOULAC	5036.	.06
H2SO4	244.	.00
K AMYL XANTHATE	990.	.01
MIC	1320.	.01
LIME	90042.	.99
TOTAL FOR PLANT	9066950.	100.00

UNIT ENERGY REQUIREMENT 90.6695 MMBTU PER TON COPPER

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The use of electric furnaces for the smelting of copper has only recently been adopted by copper companies in this country. In 1970 Cities Service Co., at Copperhill, Tenn., was the first. In its operation, 300 tons per day of chalcopyrite concentrates are calcined in a fluid-bed roaster and the calcine is fed to an 8,000-kilovolt-ampere (kVA) furnace to make matte that is converted to 80 tons per day of blister copper. The second electric furnace was built at Inspiration Consolidated Copper Co.'s plant at Inspiration, Ariz. in 1974. This unit, which is the largest in the world, operates on 51,000 kVA and smelts 1,500 tons per day of concentrate to produce about 500 tons of blister copper per day. The latest electric furnace, presently operating, is at Anaconda, Mont.

Economic evaluations were made of two versions of electric smelters, one using a sulfuric acid plant for removing sulfur from the offgas and the other using a Bureau of Mines citrate process plant. Green feed, which is the same for both modifications, is dried in a rotary drier to less than 0.4 percent moisture. Feed rate of dry concentrate is 1,142.9 tons per day. The feed together with 127.2 tons per day of quartzite and limerock fluxes is fed to the electric furnace which produces 1,014 tons per day of matte containing 32 percent copper and 836.9 tons per day of slag. Offgas from the electric furnace containing 5.5 percent SO_2 is passed successively through waste heat boilers, cyclones, and an electrostatic precipitator before being blended with converter gas. The resulting gas, which is treated for sulfur dioxide removal, contains 4.0 percent SO_2. Slag from the electric furnace containing 0.55 percent copper and 1.0 percent sulfur is discarded.

The matte, together with 199.5 tons per day of siliceous fluxes, is fed to a converter producing 304.2 tons per day of blister copper. Converter gas is cooled by infiltration of air and passed through an electrostatic precipitator before mixing with gas from the electric furnace.

Blister copper from the converter, containing 99.4 percent Cu, is sent to an anode furnace at a rate of 304.2 tons per day. Anodes go to the electrolytic refinery where 303 tons per day (100,000 tons per year) of electrolytic copper are produced.

Gas to Acid Plant

An electric furnace smelter with a 23,800-kVA electric furnace[18] is used in this evaluation. The combined electric furnace and converter offgases go to a 1,350-ton-per-day-capacity, double-contact acid plant that recovers 1,043.2 tons per day byproduct acid. This modification recovers 88.97 percent of the 382.9 tons per day of sulfur in the feed as sulfuric acid. The balance of the sulfur, in percent, is distributed as follows: 2.38 in slag, 0.13 in fugitive dust, and 2.85 in fugitive gas (both as leakage within the smelter), 4.73 as neutralized acid sludge, and 0.94 up the stack. A materials balance flowsheet for this process is shown in Figure 10, and costs and energy requirements are presented in Tables 26 through 28.

[18] Herbert, I. C., Extractive Metallurgy, Mining Annual Review, July 20, 1973, pp. 227-253.

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(4-76)

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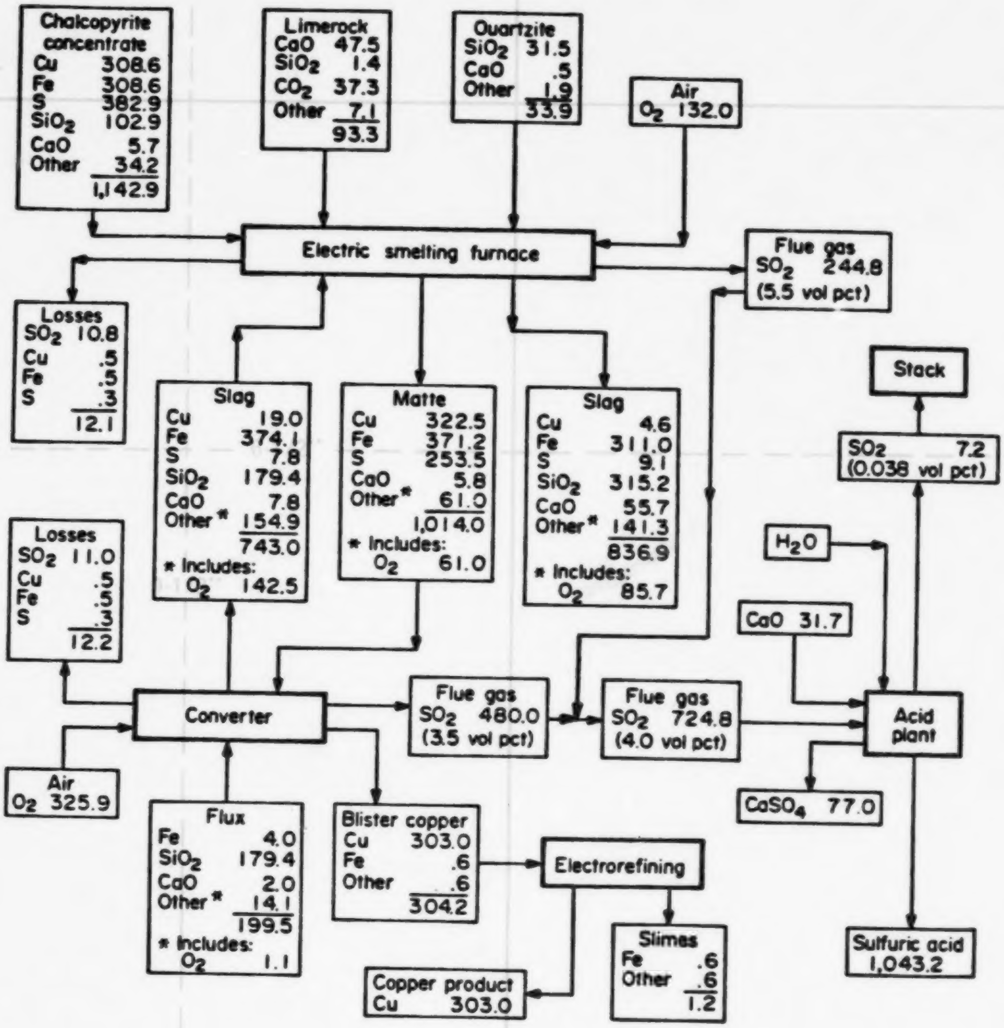
Chalcopyrite concentrate
Cu 308.6
Fe 308.6
S 382.9
SiO2 102.9
CaO 5.7
Other 34.2
1,142.9
Limerock
CaO 47.5
SiO2 1.4
CO2 37.3
Other 7.1
93.3
Quartzite
SiO2 31.5
CaO .5
Other 1.9
33.9
Air
O2 132.0
Electric smelting furnace
Flue gas
SO2 244.8
(5.5 vol pct)
Losses
SO2 10.8
Cu .5
Fe .5
S .3
12.1
Slag
Cu 19.0
Fe 374.1
S 7.8
SiO2 179.4
CaO 7.8
Other* 154.9
743.0
* Includes:
O2 142.5
Matte
Cu 322.5
Fe 371.2
S 253.5
CaO 5.8
Other* 61.0
1,014.0
* Includes:
O2 61.0
Slag
Cu 4.6
Fe 311.0
S 9.1
SiO2 315.2
CaO 55.7
Other* 141.3
836.9
* Includes:
O2 85.7
Stack
SO2 7.2
(0.038 vol pct)
H2O
CaO 31.7
Losses
SO2 11.0
Cu .5
Fe .5
S .3
12.2
Converter
Flue gas
SO2 480.0
(3.5 vol pct)
Flue gas
SO2 724.8
(4.0 vol pct)
Acid plant
Air
O2 325.9
CaSO4 77.0
Flux
Fe 4.0
SiO2 179.4
CaO 2.0
Other* 14.1
199.5
* Includes:
O2 1.1
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Slimes
Fe .6
Other .6
1.2
Sulfuric acid
1,043.2
Copper product
Cu 303.0

FIGURE 10.- Material balance and flow diagram for electric furnace process with a sulfuric acid plant for the offgas. (tons per day)

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TABLE 26. - Annual operating cost, $, of unit operations for electric furnace copper smelter with acid plant

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	OPERATING COST, PCT
DIRECT COST				
MATERIALS				
LIMESTONE	30775.9 TON	10.00	307800.	.38
QUARTZITE	11201.6 TON	10.00	112000.	.14
GRAPHITE PASTE	1885785.0 LB	.26	490300.	.61
CONVERTER FLUX	65785.9 TON	10.00	657900.	.82
LEAD ANODE	105.6 TON	3089.00	326300.	.41
GLUE	5049.8 LB	.90	4500.	.01
GOULAC	251777.8 LB	.15	37800.	.05
H2SO4	294.1 TON	20.00	5900.	.01
LIME	10487.4 TON	53.40	560000.	.70
TOTAL			2502500.	3.13
UTILITIES				
ELECTRICITY	289910.4570 MKWHR	40.00	11596400.	14.49
NATURAL GAS, CONSUMED	1198447.2 MCF	3.15	3775100.	4.71
WATER, PROCESS	110291.9 MGAL	.34	37500.	.05
WATER, COOLING	749659.7 MGAL	.06	45000.	.06
STEAM	1053600.4 MLB	4.22	4446200.	5.55
CREDIT FOR STEAM	1053590.2 MLB	-4.22	-4446200.	-5.55
TOTAL			15454000.	19.31
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4472900.	5.59
SUPERVISION .150			670900.	.84
TOTAL, D			5143800.	6.43
PLANT MAINTENANCE				
LABOR			4290600.	5.36
SUPERVISION .200			858000.	1.07
MATERIALS			6435900.	8.05
TOTAL, M			11584500.	14.48
PAYROLL OVERHEAD .600(PAYROLL)			6175500.	7.72
OPERATING SUPPLIES, S .200(M)			2317000.	2.90
TOTAL DIRECT COST			43177300.	53.96
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			7618100.	9.52
FIXED COST				
TAXES AND INSURANCE .020			5183300.	6.48
DEPRECIATION 12.500 YR			24042300.	30.03
TOTAL			29225600.	36.52
TOTAL ANNUAL OPERATING COST			80021000.	100.00

CRUSH,STORE,DRY,SMELT,CONVERT,ELECTROREFINE,
ACID PLANT, 4% SO2
CU- 22. 1 6
12.5 YR DEPRECIATION
REVISED COST (ASARCO)

JULY 31, 1980

COPPER 99999.9 TON PER YEAR

ESTIMATE 195.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	209000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	4665000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	13337000.
TOTAL	18211000.

TABLE 27. - Summary of costs and operating personnel for electric furnace copper smelter with acid plant

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20387300.	4916000.	6.14	.02458
ELECTRO SMELTING	45.0	56845000.	21414700.	26.76	.10707
CONVERTING	25.0	38627900.	11298700.	14.12	.05649
ANODE CASTING	17.0	13789700.	4096300.	5.12	.02048
ELECTROLYTIC REFINING	106.0	72943500.	26298400.	32.86	.13149
CONTACT ACID PLANT	12.0	43741600.	11996900.	14.99	.05998
TOTAL, T		246335000.			
FACILITIES,.100(T)		24633500.			
UTILITIES,.120(T)		29560500.			
TOTAL FIXED CAPITAL		300529000.			
WORKING CAPITAL		18211000.			
TOTAL CAPITAL	224.0	318740000.	80021000.	100.00	.40011

CRUSH,STORE,DRY,SMELT,CONVERT,ELECTROREFINE,
ACID PLANT, 4% SO2
CU- 22. 1 6
12.5 YR DEPRECIATION
REVISED COST (ASARCO)

JULY 31, 1980

13.03436,	$/ TON	CU CONCENTRATE
63.99707,	$/ TON	MATTE
112.53405,	$/ TON	BLISTER CU
40.79878,	$/ TON	BLISTER CU
262.98426,	$/ TON	COPPER
34.84878,	$/ TON	H2SO4

COPPER 99999.9 TON PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

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TABLE 28. - Summary of energy requirements for electric furnace copper smelter with acid plant

CRUSH,STORE,DRY,SMELT,CONVERT,ELECTROREFINE,
ACID PLANT, 4% SO2
CU- 22. 1 6
12.5 YR DEPRECIATION
REVISED COST (ASARCO)
JULY 31, 1980

COPPER 99999.9 TON PER YEAR

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8815.	.20
ELECTRO SMELTING	1627569.	36.19
CONVERTING	459151.	10.21
ANODE CASTING	160762.	3.57
ELECTROLYTIC REFINING	1680172.	37.36
CONTACT ACID PLANT	560385.	12.46
TOTAL FOR PLANT	4496855.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	134039.	2.98
ELECTRICITY INT V	942923.	20.97
ELECTRICITY LINE V	1967097.	43.74
NATURAL GAS	1198447.	26.65
STEAM	1475041.	32.80
STEAM	-1475026.	-32.80
LIMESTONE	3201.	.07
QUARTZITE	470.	.01
GRAPHITE PASTE	150129.	3.34
CONVERTER FLUX	3158.	.07
LEAD ANODE	2852.	.06
GLUE	101.	.00
GOULAC	5036.	.11
H2SO4	244.	.01
LIME	89143.	1.98
TOTAL FOR PLANT	4496855.	100.00

UNIT ENERGY REQUIREMENT 44.9686 MMBTU PER TON COPPER

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Gas to Citrate Process Plant

The second evaluation covers an electric furnace smelting process identical to the one used in the first evaluation except that a Bureau of Mines citrate process plant is used to treat the offgas. This modification recovers 88.04 percent of the sulfur in the feed, 337.1 tons per day, as elemental sulfur. The balance of the sulfur, in percent, is distributed as follows: 2.38 in slag, 0.13 in fugitive dust and 2.85 in fugitive gas (both as leakage within the smelter), 4.73 as neutralized acid sludge, 0.93 as Glauber's salt, and 0.94 up the stack. A materials balance flowsheet for this process is shown in Figure 11, and costs and energy requirements are presented in tables 29 through 31.

6. CONVENTIONAL REVERBERATORY FURNACE PROCESS

Although most of the newer smelters are based on emerging technology that incorporates more efficient SO_2 recovery systems, the conventional reverberatory furnace is still used in the majority of copper smelters in the world. The replacement of these furnaces by more modern units to meet environmental requirements will entail a high cost. These scenarios examine the economics of auxiliary SO_2 control systems that may be added to a conventional reverberatory smelter.

In a conventional reverberatory smelter without SO_2 removal systems, temperatures of offgases are lowered to 600° to 700° F by passing them through waste heat boilers and then to about 250° F by infiltration of cooler gas streams (e.g., ventilation gases). A large part of the dust containing most of the minor volatile elements such as arsenic, mercury, lead, zinc, cadmium, and bismuth settles in the flues, and most of the remaining dust is removed by an electrostatic precipitator. These dusts are recycled to the reverberatory furnace, but in some cases a bleed off is used to prevent an impurity buildup. Some of the volatile elements escape as fumes. Theoretical studies have been made for estimating the volatile element content of smelter gases,[19] but actual operating data are not available.

Systems for the control of SO_2 require complete cleaning of the gas, and, therefore, make possible the removal of more of the minor elements in the dust and fume. Some of the processes based on making acid treat only part of the gas, and some of the newer and unproven processes may be able to treat all of it.

Economic evaluations were made for five process scenarios including a conventional smelter with no pollution controls and four modifications using SO_2 control systems. These modifications included (1) a conventional copper smelter with converter gas going to an acid plant, (2) a conventional copper smelter with converter gas going to an acid plant and reverberatory gases

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[19] Yazawa, A. and T. Azakami. Thermodynamics of Removing Impurities During Copper Smelting. Can. Met. Quart., v. 8, No. 3, 257 (1969).

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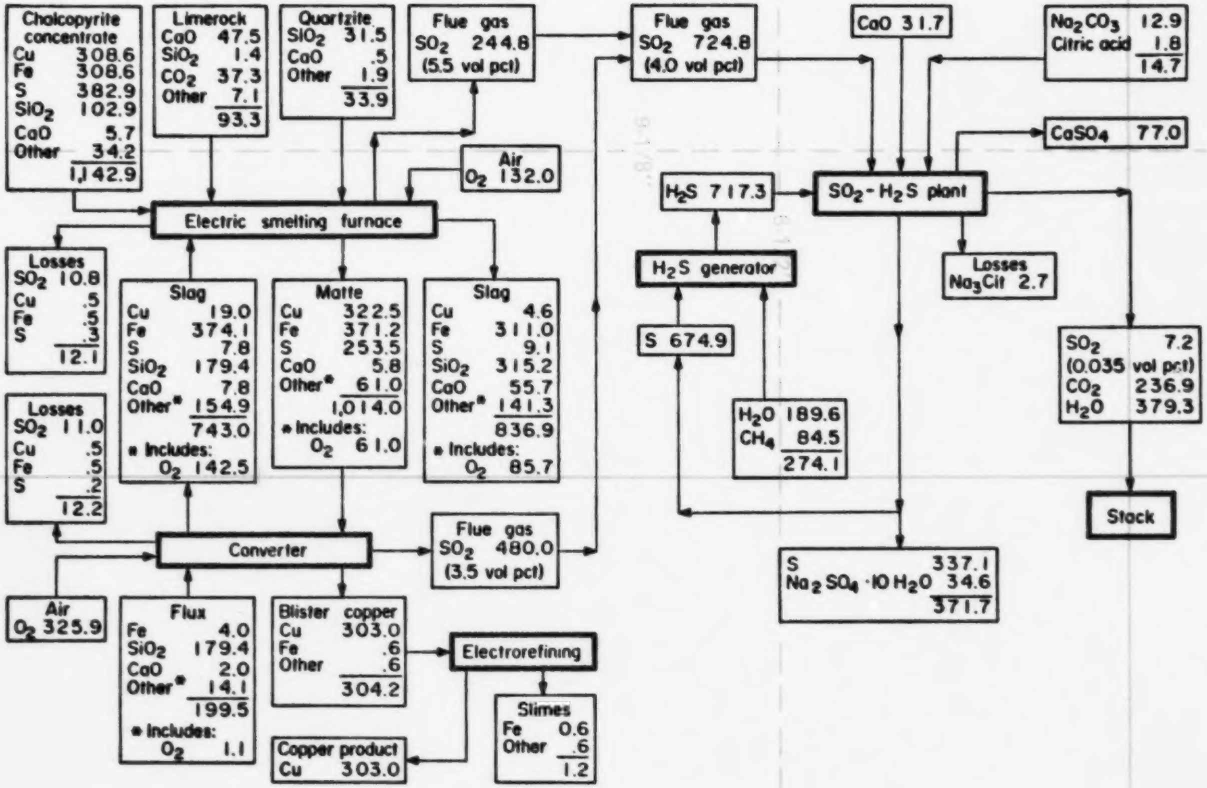
Chalcopyrite concentrate
Cu 308.6
Fe 308.6
S 382.9
SiO2 102.9
CaO 5.7
Other 34.2
1,142.9
Limerock
CaO 47.5
SiO2 1.4
CO2 37.3
Other 7.1
93.3
Quartzite
SiO2 31.5
CaO .5
Other 1.9
33.9
Flue gas
SO2 244.8
(5.5 vol pct)
Air
O2 132.0
Electric smelting furnace
Losses
SO2 10.8
Cu .5
Fe .5
S .3
12.1
Slag
Cu 19.0
Fe 374.1
S 7.8
SiO2 179.4
CaO 7.8
Other* 154.9
743.0
* Includes:
O2 142.5
Matte
Cu 322.5
Fe 371.2
S 253.5
CaO 5.8
Other* 61.0
1,014.0
* Includes:
O2 61.0
Slag
Cu 4.6
Fe 311.0
S 9.1
SiO2 315.2
CaO 55.7
Other* 141.3
836.9
* Includes:
O2 85.7
Losses
SO2 11.0
Cu .5
Fe .5
S .2
12.2
Converter
Flue gas
SO2 480.0
(3.5 vol pct)
Air
O2 325.9
Flux
Fe 4.0
SiO2 179.4
CaO 2.0
Other* 14.1
199.5
* Includes:
O2 1.1
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Copper product
Cu 303.0
Slimes
Fe 0.6
Other .6
1.2
Flue gas
SO2 724.8
(4.0 vol pct)
CaO 31.7
Na2CO3 12.9
Citric acid 1.8
14.7
CaSO4 77.0
H2S 717.3
SO2 - H2S plant
H2S generator
Losses
Na3Cit 2.7
S 674.9
H2O 189.6
CH4 84.5
274.1
SO2 7.2
(0.035 vol pct)
CO2 236.9
H2O 379.3
Stack
S 337.1
Na2SO4 · 10 H2O 34.6
371.7

FIGURE 11.- Material balance and flow diagram for electric furnace process with Bureau of Mines citrate process for the offgas. (tons per day)

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TABLE 29. - Annual operating cost, $, of unit operations for electric furnace copper smelter with Bureau of Mines citrate process

```
---------------------------------------------------------------------------
                                  ANNUAL           UNIT      OPERATING COST,
                                CONSUMPTION        COST         $       PCT
---------------------------------------------------------------------------
DIRECT COST
  MATERIALS
    LIMESTONE                     30775.9 TON      10.00      307800.     .32
    QUARTZITE                     11201.6 TON      10.00      112000.     .12
    GRAPHITE PASTE              1885785.0 LB         .14      256500.     .27
    CONVERTER FLUX                65785.9 TON      10.00      657900.     .69
    LEAD ANODE                      105.6 TON    3089.00      326300.     .34
    GLUE                           5049.8 LB         .90        4500.     .00
    GOULAC                       251777.8 LB         .15       37800.     .04
    H2SO4                           294.1 TON      20.00        5900.     .01
    LIME                          10487.4 TON      53.40      560000.     .59
    CITRIC ACID                     586.1 TON    1360.00      797100.     .84
    SODA ASH                       4244.4 TON      60.00      254600.     .27
    KEROSINE                     164752.6 GAL        .95      156500.     .16
                                                          ------------ ------
        TOTAL                                                3476900.    3.65
  UTILITIES                                               ============ ======
    ELECTRICITY              268974.6836 MKWHR     40.00    10759000.   11.28
    NATURAL GAS, CONSUMED      5053656.9 MCF        3.15    15919000.   16.69
    WATER, PROCESS               86194.0 MGAL        .34       29300.     .03
    WATER, COOLING             7834389.2 MGAL        .06      470100.     .49
    STEAM                      1718495.4 MLB        4.22     7252200.    7.60
    CREDIT FOR STEAM           1754298.5 MLB       -4.22    -7403200.   -7.75
                                                          ------------ ------
        TOTAL                                               27026400.   28.34
  DIRECT LABOR                                            ============ ======
    LABOR   9.600/MAN HOUR                                   4572700.    4.80
    SUPERVISION   .150                                        686000.     .72
                                                          ------------ ------
        TOTAL, D                                             5258700.    5.52
  PLANT MAINTENANCE                                       ============ ======
    LABOR                                                    4496100.    4.72
    SUPERVISION   .200                                        899100.     .94
    MATERIALS                                                6744100.    7.07
                                                          ------------ ------
        TOTAL, M                                            12139300.   12.73
  PAYROLL OVERHEAD   .600(PAYROLL)                           6392300.    6.70
  OPERATING SUPPLIES, S   .200(M)                            2428000.    2.55
                                                          ============ ======
        TOTAL DIRECT COST                                   56721600.   59.48
INDIRECT COST
  ADMINISTRATION AND OVERHEAD   .400(D+M+S)                  7930400.    8.32
FIXED COST                                                ============ ======
  TAXES AND INSURANCE   .020                                 5486900.    5.75
  DEPRECIATION 12.500 YR                                    25211100.   26.44
                                                          ------------ ------
        TOTAL                                               30698000.   32.20
                                                          ============ ======
        TOTAL ANNUAL OPERATING COST                         95350000.  100.00
```

```
CRUSH,STORE,DRY,SMELT,CONVERT,ELECTROREFINE,

                 CU- 22.  2 6
CITRATE PLANT, 4.0% SO2

                        JULY 31, 1980


COPPER                        99999.9 TON   PER YEAR


ESTIMATE  205.0 MAINT. MEN,  10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH


                WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS =
  (TOTAL ANNUAL MATERIAL COST)/12              290000.
1 MONTH'S OUT-OF-POCKET EXPENSE =
  (TOTAL AN OP COST-DEPRECIATION)/12          5845000.
2 MONTH'S PRODUCT INVENTORY =
  (TOTAL ANNUAL OPERATING COST)/6            15892000.
                                          -------------
  TOTAL                                      22027000.
```

TABLE 30. - Summary of costs and operating personnel for electric furnace copper smelter with Bureau of Mines citrate process

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20387300.	4914300.	5.15	.02457
ELECTRO SMELTING	45.0	56845000.	20241800.	21.23	.10121
CONVERTING	25.0	38627900.	11221200.	11.77	.05611
ANODE CASTING	17.0	13789700.	4057200.	4.26	.02029
ELECTROLYTIC REFINING	106.0	73523700.	25616600.	26.87	.12808
GAS COOLING & CLEANING	2.1	13546500.	4042200.	4.24	.02021
ABSORPTION	2.1	2262800.	2243800.	2.35	.01122
SULFUR PRECIPITATION	4.2	1286700.	581200.	.61	.00291
SULFUR RECOVERY	2.1	7944400.	2144500.	2.25	.01072
H2S GENERATION	4.3	27158100.	19272800.	20.21	.09636
SODIUM SULFATE REMOVAL	2.2	2975500.	1014400.	1.06	.00507
TOTAL, T		258347600.			
INITIAL REAGENTS, IR = 199400.					
FACILITIES,.100(T-IR)		25814800.			
UTILITIES,.120(T-IR)		30977600.			
TOTAL FIXED CAPITAL		315140000.			
WORKING CAPITAL		22027000.			
TOTAL CAPITAL	229.0	337167000.	95350000.	100.00	.47675

CRUSH,STORE,DRY,SMELT,CONVERT,ELECTROREFINE,

CU- 22. 2 G
CITRATE PLANT, 4.0% SO2

JULY 31, 1980

13.02985,	$/ TON	CU CONCENTRATE
60.49190,	$/ TON	MATTE
111.76216,	$/ TON	BLISTER CU
40.40935,	$/ TON	BLISTER CU
256.16626,	$/ TON	COPPER
.05706,	$/ MSCF	FLUE GAS, 4.4% SO2
18.93138,	$/ TON	SULFUR
4.90370,	$/ TON	SULFUR
21.59352,	$/ LTON	SULFUR
81.42094,	$/ TON	H2S
88.76778,	$/ TON	GLAUBER'S SALT

COPPER 99999.9 TON PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

EPA-287 (Cin.)
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TABLE 31. - Summary of energy requirements for electric furnace copper smelter with Bureau of Mines citrate process

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8815.	.11
ELECTRO SMELTING	1627569.	19.92
CONVERTING	459151.	5.62
ANODE CASTING	160762.	1.97
ELECTROLYTIC REFINING	1633457.	20.00
GAS COOLING & CLEANING	150453.	1.84
ABSORPTION	275964.	3.38
SULFUR PRECIPITATION	31515.	.39
SULFUR RECOVERY	105394.	1.29
H2S GENERATION	3637563.	44.53
SODIUM SULFATE REMOVAL	78251.	.96
TOTAL FOR PLANT	8168895.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	270258.	3.31
ELECTRICITY INT V	586878.	7.18
ELECTRICITY LINE V	1967097.	24.08
NATURAL GAS	5053657.	61.86
STEAM	2405893.	29.45
STEAM	-2456018.	-30.07
LIMESTONE	3201.	.04
QUARTZITE	470.	.01
GRAPHITE PASTE	150129.	1.84
CONVERTER FLUX	3158.	.04
LEAD ANODE	2852.	.03
GLUE	101.	.00
GOULAC	5036.	.06
H2SO4	244.	.00
LIME	89143.	1.09
CITRIC ACID	5861.	.07
SODA ASH	77672.	.95
KEROSINE	3262.	.04
TOTAL FOR PLANT	8168895.	100.00

UNIT ENERGY REQUIREMENT 81.6890 MMBTU PER TON COPPER

CRUSH,STORE,DRY,SMELT,CONVERT,ELECTROREFINE,

CU- 22. 2 6
CITRATE PLANT, 4.0% SO2

JULY 31, 1980

COPPER 99999.9 TON PER YEAR

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going to a Bureau of Mines citrate process plant, (3) a conventional copper smelter with both converter and reverberatory gases going to a Bureau of Mines citrate process plant, and (4) a conventional copper smelter with a roaster in which roaster and converter gases go to an acid plant.

All five versions of the process use 1,143 tons per day of concentrate feed on a dry basis. In addition, the feed includes 127 tons of quartzite and limerock fluxes for the first four versions without the roaster and 195.6 tons of flux for the version with the roaster. In the first four versions of the process, the feed goes directly into a reverberatory furnace to produce 1,014 tons per day of matte containing 32 percent copper. In the fifth version the feed is roasted in a fluidized bed reactor to eliminate 33.4 percent of the sulfur prior to charging the reverberatory furnace. In this case, 789.8 tons per day of matte containing 40 percent copper is produced. The reverberatory furnace is fired with natural gas in all five versions, and the offgas, which would actually contain varying amounts of SO_2, was assumed to contain 2.0 percent SO_2. Also included in the reverberatory feed for the respective processes are 743 tons per day of recycle converter slag containing 2.56 percent copper for the first four versions and 476 tons per day containing 1.05 percent copper for the fifth version. The respective reverberatory operations discard 836.9 and 833.8 tons per day of slag containing 0.55 percent copper.

Matte from the reverberatory furnaces goes to converters together with flux. Although in industrial practice other materials are added to the converters such as dust, scrap, and spills, calculations on such additions have been omitted in the interest of simplification. In the first four versions of the process, 1,014 tons per day of matte and 199.5 tons of siliceous flux are charged to the converter. For the fifth version, the respective charges are 789.8 and 128 tons per day. In all cases the converter product is 304.2 tons per day of 99.6 percent blister copper.

Blister copper is transferred to an anode furnace where it is further refined and cast into anodes. These anodes go to the electrolytic cells in the refinery where 303 tons per day (100,000 tons per 330-day year) of electrolytic copper are produced.

--With No SO_2 Controls

The first scenario is for a conventional smelter operating with green feed and with no provisions for controlling SO_2 emissions. In this operation, 100 percent of the 724.8 tons per day of sulfur dioxide in the reverberatory and converter gases goes up the stack. This is 94.64 percent of the 382.9 tons per day of sulfur in the feed. The balance of the sulfur is distributed as follows, in percent: 2.38 in slag and 2.98 as leakage within the smelter (2.85 as fugitive gas and 0.13 as fugitive dust and fumes). A materials balance flowsheet for this process is shown in Figure 12, and costs and energy requirements are presented in Tables 32 through 34.

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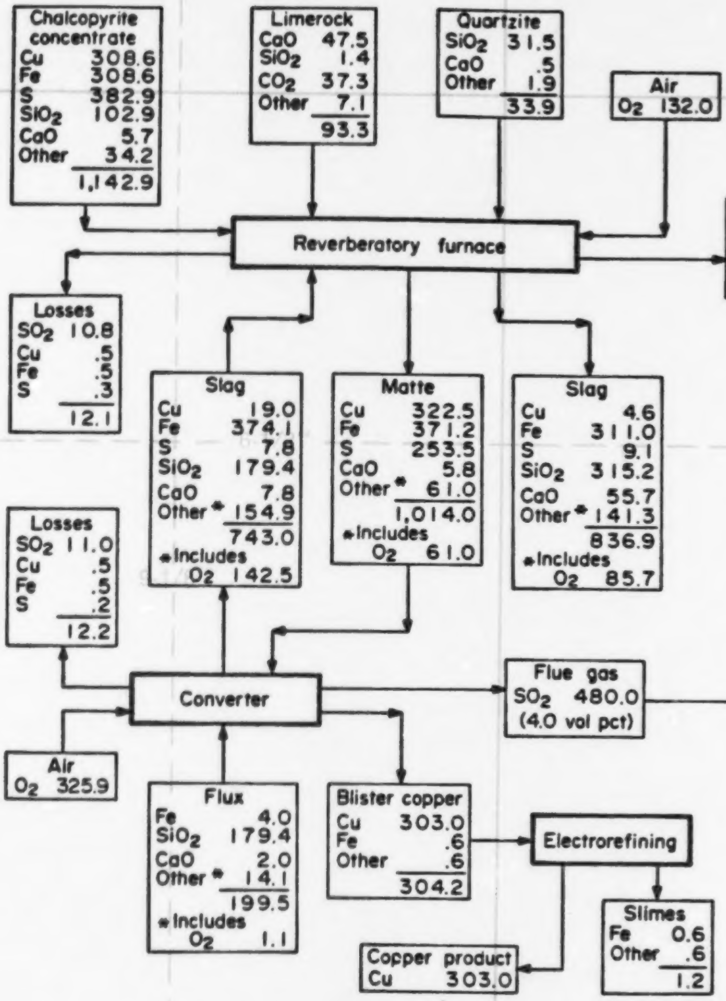
Chalcopyrite concentrate
Cu 308.6
Fe 308.6
S 382.9
SiO2 102.9
CaO 5.7
Other 34.2
1,142.9
Limerock
CaO 47.5
SiO2 1.4
CO2 37.3
Other 7.1
93.3
Quartzite
SiO2 31.5
CaO .5
Other 1.9
33.9
Air
O2 132.0
Reverberatory furnace
Flue gas
SO2 244.8
(2.0 vol pct)
CO2 37.3
Losses
SO2 10.8
Cu .5
Fe .5
S .3
12.1
Slag
Cu 19.0
Fe 374.1
S 7.8
SiO2 179.4
CaO 7.8
Other* 154.9
743.0
*Includes O2 142.5
Matte
Cu 322.5
Fe 371.2
S 253.5
CaO 5.8
Other* 61.0
1,014.0
*Includes O2 61.0
Slag
Cu 4.6
Fe 311.0
S 9.1
SiO2 315.2
CaO 55.7
Other* 141.3
836.9
*Includes O2 85.7
Stack
SO2 724.8
(2.7 vol pct)
Losses
SO2 11.0
Cu .5
Fe .5
S .2
12.2
Converter
Flue gas
SO2 480.0
(4.0 vol pct)
Air
O2 325.9
Flux
Fe 4.0
SiO2 179.4
CaO 2.0
Other* 14.1
199.5
*Includes O2 1.1
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Slimes
Fe 0.6
Other .6
1.2
Copper product
Cu 303.0

FIGURE 12.-Material balance and flow diagram for conventional copper smelter with no SO_2 control. (tons per day)

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TABLE 32. - Annual operating cost, $, of unit operations for conventional copper smelter with no SO_2 control

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	PCT
DIRECT COST				
MATERIALS				
LIMESTONE	30775.9 TON	10.00	307800.	.44
QUARTZITE	11201.6 TON	10.00	112000.	.16
CONVERTER FLUX	65785.9 TON	10.00	657900.	.96
LEAD ANODE	105.6 TON	3089.00	326300.	.47
GLUE	5049.8 LB	.90	4500.	.01
GOULAC	251777.8 LB	.15	37800.	.05
H2SO4	294.1 TON	20.00	5900.	.01
TOTAL			1452200.	2.10
UTILITIES				
ELECTRICITY	75419.4707 MKWHR	40.00	3016800.	4.36
NATURAL GAS, CONSUMED	3038623.4 MCF	3.15	9571700.	13.83
WATER, PROCESS	81436.0 MGAL	.34	27700.	.04
STEAM	1053600.0 MLB	4.22	4446200.	6.42
CREDIT FOR STEAM	1053570.0 MLB	-4.22	-4446100.	-6.42
TOTAL			12616300.	18.23
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4393000.	6.35
SUPERVISION .150			658900.	.95
TOTAL, D			5051900.	7.30
PLANT MAINTENANCE				
LABOR			3727600.	5.39
SUPERVISION .200			745400.	1.08
MATERIALS			5591200.	8.08
TOTAL, M			10064200.	14.55
PAYROLL OVERHEAD .600(PAYROLL)			5714900.	8.26
OPERATING SUPPLIES, S .200(M)			2013000.	2.91
TOTAL DIRECT COST			36912500.	53.35
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			6851600.	9.90
FIXED COST				
TAXES AND INSURANCE .020			4546600.	6.57
DEPRECIATION 12.500 YR			20882300.	30.18
TOTAL			25428900.	36.75
TOTAL ANNUAL OPERATING COST			69193000.	100.00

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE
CU REC. = 98.28
CU- 15. 1 6
12.5 YR DEPRECIATION
BASED ON ASARCO COSTS

JULY 31, 1980

COPPER	99999.9 TON PER YEAR

ESTIMATE 170.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	121000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	4026000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	11532000.
TOTAL	15679000.

TABLE 33. - Summary of costs and operating personnel for conventional copper smelter with no SO_2 control

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20387300.	4918100.	7.11	.02459
MATTE SMELTING	53.0	68227800.	21482000.	31.05	.10741
CONVERTING	25.0	38627900.	11605400.	16.77	.05803
ANODE CASTING	17.0	13789700.	4153300.	6.00	.02077
ELECTROLYTIC REFINING	106.0	72924600.	27034200.	39.07	.13517
TOTAL, T		213957300.			
FACILITIES,.100(T)		21395700.			
UTILITIES,.120(T)		25675000.			
TOTAL FIXED CAPITAL		261028000.			
WORKING CAPITAL		15679000.			
TOTAL CAPITAL	220.0	276707000.	69193000.	100.00	.34597

```
CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE
                        CU REC. = 98.28
              CU- 15.  1 G
12.5 YR DEPRECIATION
     BASED ON ASARCO COSTS

                 JULY 31, 1980

       13.03993, $/ TON    CU CONCENTRATE
       64.19819, $/ TON    MATTE
      115.58875, $/ TON    BLISTER CU
       41.36650, $/ TON    BLISTER CU
      270.34227, $/ TON    COPPER



COPPER                    99999.9 TON   PER YEAR


U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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TABLE 34. - Summary of energy requirements for conventional copper smelter with no SO_2 control

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE
CU REC. = 98.21
CU- 15. 1 6
12.5 YR DEPRECIATION
BASED ON ASARCO COSTS
JULY 31, 1980

COPPER 99999.9 TON PER YEAR

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8815.	.23
MATTE SMELTING	1512387.	39.33
CONVERTING	459151.	11.94
ANODE CASTING	160762.	4.18
ELECTROLYTIC REFINING	1704515.	44.32
TOTAL FOR PLANT	3845631.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	133860.	3.48
ELECTRICITY INT V	473014.	12.30
ELECTRICITY LINE V	185031.	4.81
NATURAL GAS	3038623.	79.01
STEAM	1475040.	38.36
STEAM	-1474998.	-38.36
LIMESTONE	3201.	.08
QUARTZITE	470.	.01
CONVERTER FLUX	3158.	.08
LEAD ANODE	2852.	.07
GLUE	101.	.00
GOULAC	5036.	.13
H2SO4	244.	.01
TOTAL FOR PLANT	3845631.	100.00

UNIT ENERGY REQUIREMENT 38.4563 MMBTU PER TON COPPER

EPA-287 (Cin.)
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--With Converter Gas to Acid Plant

The second scenario is for a conventional copper smelter operating under the same conditions as in the first evaluation, but with the converter gas going to a 1,000-ton-per-day capacity acid plant. The acid plant produces 690.8 tons of byproduct acid per day. The addition of an acid plant results in the recovery of 58.92 percent of the 382.9 tons per day of sulfur in the feed as acid. The balance of the sulfur is distributed as follows, in percent: 2.38 in slag, 3.13 as neutralized acid sludge, 2.98 as leakage within the smelter (2.85 as fugitive gas and 0.13 as fugitive dust and fume), and 32.59 up the stack (31.97 in reverberatory gas and 0.62 in acid plant offgas). A materials balance flowsheet for this process is shown in Figure 13, and costs and energy requirements are presented in Tables 35 through 37.

--With Converter Gas to Acid Plant and Reverberatory Gas to Bureau of Mines Citrate Process Plant

The third scenario is for a conventional copper smelter in which the reverberatory furnace gas goes to a Bureau of Mines citrate process plant that recovers 114.1 tons of elemental sulfur per day, and the converter gas goes to a 1,000-ton-per-day capacity acid plant that recovers 690.8 tons of byproduct acid per day. These added unit operations recover 88.70 percent of the 382.9 tons per day of sulfur in the feed, 58.90 percent as acid and 29.80 percent as elemental sulfur. The balance of the sulfur is distributed as follows, in percent: 2.38 in slag, 2.98 as leakage within the smelter (2.85 as fugitive gas and 0.13 as fugitive dust and fume), 0.31 as Glauber's salt, 4.74 as neutralized acid sludge, and 0.89 up the stack (0.63 in acid plant offgas and 0.23 in citrate plant offgas). A materials balance flowsheet for this process is shown in Figure 14, and costs and energy requirements are presented in Tables 38 through 40.

--With Converter and Reverberatory Gas to Bureau of Mines Citrate Process Plant

The fourth scenario comprises a conventional copper smelter operating under the same conditions as the first evaluation, except that both the reverberatory furnace gas and the converter gas go to a Bureau of Mines citrate process plant that recovers 337.1 tons of elemental sulfur per day. This operations results in the recovery of 88.06 percent of the 382.9 tons per day sulfur in the feed as elemental sulfur. The balance of the sulfur is distributed as follows, in percent: 2.38 in slag, 2.98 as leakage within the smelter (2.85 as fugitive gas and 0.13 as fugitive dust and fume), 0.90 as Glauber's salt, 7.74 as neutralized acid sludge, and 0.94 up the stack. A materials balance flowsheet for this process is shown in Figure 15, and costs and energy requirements are presented in Tables 41 through 43.

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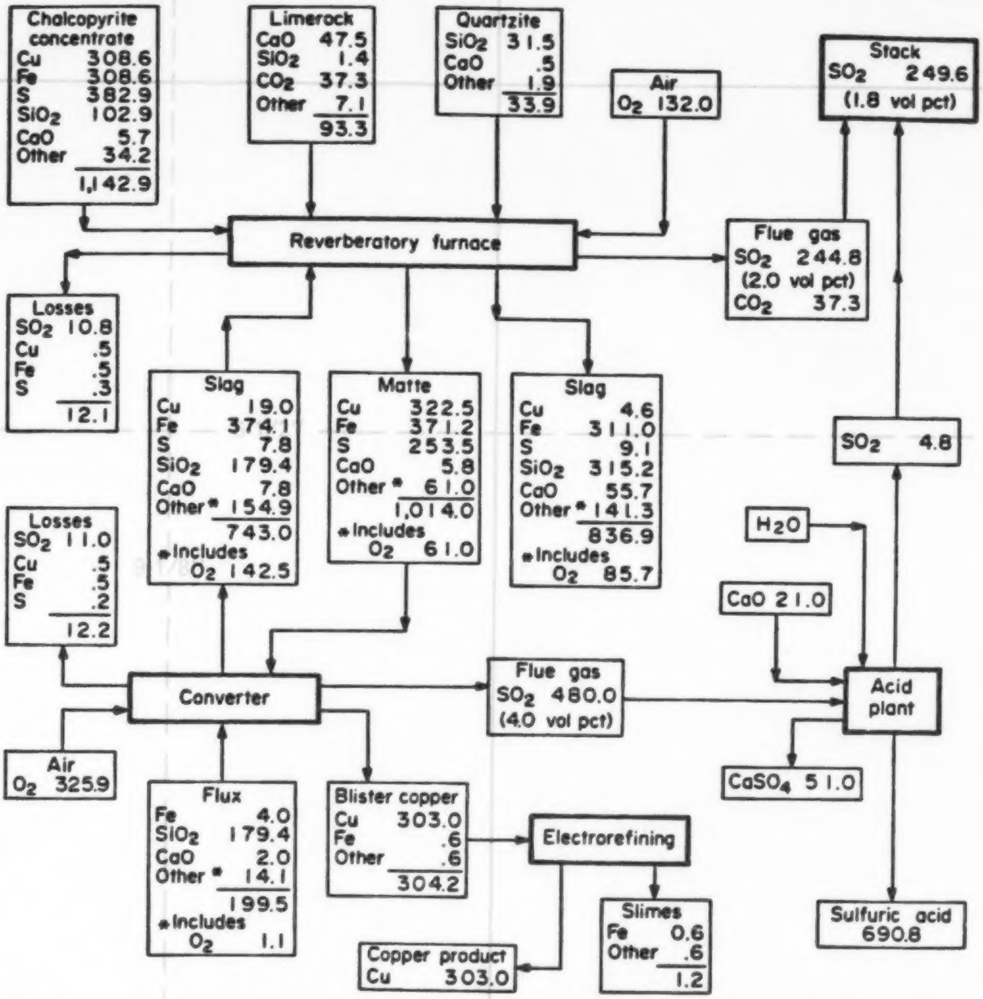
Chalcopyrite concentrate
Cu 308.6
Fe 308.6
S 382.9
SiO_2 102.9
CaO 5.7
Other 34.2
1,142.9
Limerock
CaO 47.5
SiO_2 1.4
CO_2 37.3
Other 7.1
93.3
Quartzite
SiO_2 31.5
CaO .5
Other 1.9
33.9
Air
O_2 132.0
Stack
SO_2 249.6
(1.8 vol pct)
Reverberatory furnace
Flue gas
SO_2 244.8
(2.0 vol pct)
CO_2 37.3
Losses
SO_2 10.8
Cu .5
Fe .5
S .3
12.1
Slag
Cu 19.0
Fe 374.1
S 7.8
SiO_2 179.4
CaO 7.8
Other* 154.9
743.0
*Includes O_2 142.5
Matte
Cu 322.5
Fe 371.2
S 253.5
CaO 5.8
Other* 61.0
1,014.0
*Includes O_2 61.0
Slag
Cu 4.6
Fe 311.0
S 9.1
SiO_2 315.2
CaO 55.7
Other* 141.3
836.9
*Includes O_2 85.7
SO_2 4.8
H_2O
CaO 21.0
Losses
SO_2 11.0
Cu .5
Fe .5
S .2
12.2
Converter
Flue gas
SO_2 480.0
(4.0 vol pct)
Acid plant
Air
O_2 325.9
Flux
Fe 4.0
SiO_2 179.4
CaO 2.0
Other* 14.1
199.5
*Includes O_2 1.1
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
$CaSO_4$ 51.0
Slimes
Fe 0.6
Other .6
1.2
Sulfuric acid
690.8
Copper product
Cu 303.0

FIGURE 13.- Material balance and flow diagram for conventional copper smelter with an acid plant for converter gases. (tons per day)

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TABLE 35. - Annual operating cost, $, of unit operations for conventional copper smelter with an acid plant for converter

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	PCT
DIRECT COST				
MATERIALS				
LIMESTONE	30775.9 TON	10.00	307800.	.38
QUARTZITE	11201.6 TON	10.00	112000.	.14
CONVERTER FLUX	65785.9 TON	10.00	657900.	.81
LEAD ANODE	105.6 TON	3089.00	326300.	.40
GLUE	5049.8 LB	.90	4500.	.01
GOULAC	251777.8 LB	.15	37800.	.05
H2SO4	294.1 TON	20.00	5900.	.01
LIME	6942.0 TON	53.40	370700.	.46
TOTAL			1822900.	2.26
UTILITIES				
ELECTRICITY	118409.8174 MKWHR	40.00	4736400.	5.87
NATURAL GAS, CONSUMED	3038623.4 MCF	3.15	9571700.	11.85
WATER, PROCESS	107685.5 MGAL	.34	36600.	.05
WATER, COOLING	198000.0 MGAL	.06	11900.	.01
STEAM	1053600.0 MLB	4.22	4446200.	5.50
CREDIT FOR STEAM	1053570.0 MLB	-4.22	-4446100.	-5.50
TOTAL			14356700.	17.78
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4632600.	5.74
SUPERVISION .150			694800.	.86
TOTAL, D			5327400.	6.60
PLANT MAINTENANCE				
LABOR			4472300.	5.54
SUPERVISION .200			894300.	1.11
MATERIALS			6708200.	8.30
TOTAL, M			12074800.	14.95
PAYROLL OVERHEAD .600(PAYROLL)			6416400.	7.95
OPERATING SUPPLIES, S .200(M)			2415100.	2.99
TOTAL DIRECT COST			42413300.	52.53
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			7926900.	9.82
FIXED COST				
TAXES AND INSURANCE .020			5345400.	6.62
DEPRECIATION 12.500 YR			25061400.	31.03
TOTAL			30406800.	37.66
TOTAL ANNUAL OPERATING COST			80747000.	100.00

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE, A
CID PLANT CU REC. = 98.28
CU- 15. 2 6
12.5 YR DEPRECIATION
BASED ON ASARCO COSTS

JULY 31, 1980

COPPER 99999.9 TON PER YEAR

ESTIMATE 204.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	152000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	4640000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	13458000.
TOTAL	18250000.

TABLE 36. - Summary of costs and operating personnel for conventional copper with an acid plant for converter

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20387300.	4921200.	6.09	.02461
MATTE SMELTING	53.0	68227800.	21482900.	26.61	.10741
CONVERTING	25.0	38627900.	11449300.	14.18	.05725
ANODE CASTING	17.0	13789700.	4121400.	5.10	.02061
ELECTROLYTIC REFINING	106.0	72924600.	26567200.	32.90	.13284
CONTACT ACID PLANT	12.0	42818800.	12205000.	15.12	.06103
TOTAL, T		256776100.			
FACILITIES,.100(T)		25677600.			
UTILITIES,.120(T)		30813300.			
TOTAL FIXED CAPITAL		313267000.			
WORKING CAPITAL		18250000.			
TOTAL CAPITAL	232.0	331517000.	80747000.	100.00	.40374

```
CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE,  A
     CID PLANT       CU REC. = 98.2%
              CU- 15.  2 6
12.5 YR DEPRECIATION
     BASED ON ASARCO COSTS

              JULY 31, 1980

      13.04815, $/ TON    CU CONCENTRATE
      64.20088, $/ TON    MATTE
     114.03401, $/ TON    BLISTER CU
      41.04878, $/ TON    BLISTER CU
     265.67226, $/ TON    COPPER
      53.54303, $/ TON    SULFURIC ACID


COPPER                      99999.9 TON   PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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TABLE 37. - Summary of energy requirements for conventional copper smelter with an acid plant for converter

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8815.	.20
MATTE SMELTING	1512387.	34.72
CONVERTING	459151.	10.54
ANODE CASTING	160762.	3.69
ELECTROLYTIC REFINING	1704515.	39.13
CONTACT ACID PLANT	510406.	11.72
TOTAL FOR PLANT	4356037.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	134808.	3.09
ELECTRICITY INT V	923464.	21.20
ELECTRICITY LINE V	185031.	4.25
NATURAL GAS	3038623.	69.76
STEAM	1475040.	33.86
STEAM	-1474998.	-33.86
LIMESTONE	3201.	.07
QUARTZITE	470.	.01
CONVERTER FLUX	3158.	.07
LEAD ANODE	2852.	.07
GLUE	101.	.00
GOULAC	5036.	.12
H2SO4	244.	.01
LIME	59007.	1.35
TOTAL FOR PLANT	4356037.	100.00

UNIT ENERGY REQUIREMENT 43.5604 MMBTU PER TON COPPER

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE, A
CID PLANT CU REC. = 98.2%
CU- 15. 2 6
12.5 YR DEPRECIATION
BASED ON ASARCO COSTS
JULY 31, 1980

COPPER 99999.9 TON PER YEAR

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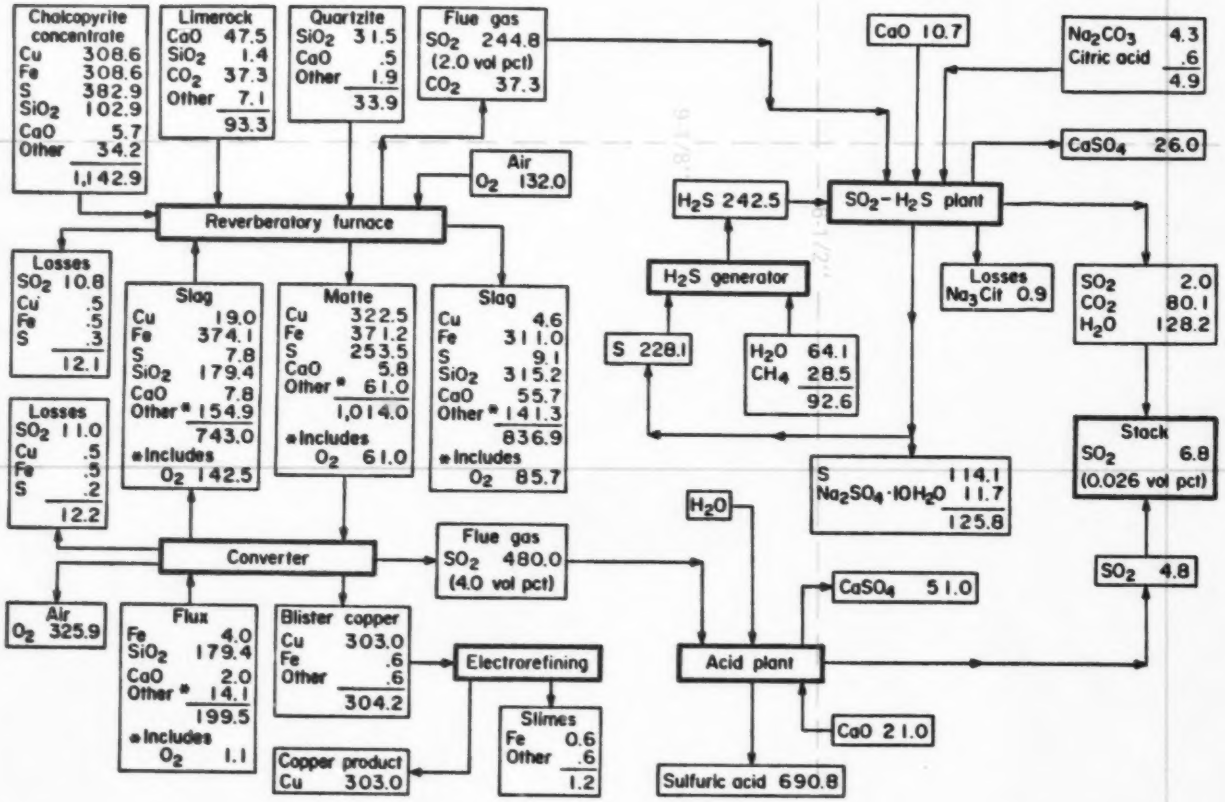
Chalcopyrite concentrate
Cu 308.6
Fe 308.6
S 382.9
SiO_2 102.9
CaO 5.7
Other 34.2
1,142.9
Limerock
CaO 47.5
SiO_2 1.4
CO_2 37.3
Other 7.1
93.3
Quartzite
SiO_2 31.5
CaO .5
Other 1.9
33.9
Flue gas
SO_2 244.8
(2.0 vol pct)
CO_2 37.3
Air
O_2 132.0
Reverberatory furnace
Losses
SO_2 10.8
Cu .5
Fe .5
S .3
12.1
Slag
Cu 19.0
Fe 374.1
S 7.8
SiO_2 179.4
CaO 7.8
Other* 154.9
743.0
*Includes O_2 142.5
Matte
Cu 322.5
Fe 371.2
S 253.5
CaO 5.8
Other* 61.0
1,014.0
*Includes O_2 61.0
Slag
Cu 4.6
Fe 311.0
S 9.1
SiO_2 315.2
CaO 55.7
Other* 141.3
836.9
*Includes O_2 85.7
Losses
SO_2 11.0
Cu .5
Fe .5
S .2
12.2
Converter
Flue gas
SO_2 480.0
(4.0 vol pct)
Air
O_2 325.9
Flux
Fe 4.0
SiO_2 179.4
CaO 2.0
Other* 14.1
199.5
*Includes O_2 1.1
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Slimes
Fe 0.6
Other .6
1.2
Copper product
Cu 303.0
H_2S 242.5
H_2S generator
S 228.1
H_2O 64.1
CH_4 28.5
92.6
CaO 10.7
Na_2CO_3 4.3
Citric acid .6
4.9
$CaSO_4$ 26.0
SO_2-H_2S plant
Losses
Na_3Cit 0.9
SO_2 2.0
CO_2 80.1
H_2O 128.2
S 114.1
$Na_2SO_4 \cdot 10H_2O$ 11.7
125.8
Stack
SO_2 6.8
(0.026 vol pct)
SO_2 4.8
H_2O
$CaSO_4$ 51.0
Acid plant
CaO 21.0
Sulfuric acid 690.8

FIGURE 14.-Material balance and flow diagram for conventional copper smelter with an acid plant for the converter gas and a Bureau of Mines citrate process plant for the reverberatory gas. (tons per day)

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TABLE 38. - Annual operating cost, $, of unit operations for conventional copper smelter with acid plant for converter and Bureau of Mines citrate plant for reverberatory

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	OPERATING COST, PCT
DIRECT COST				
MATERIALS				
LIMESTONE	30775.9 TON	10.00	307800.	.33
QUARTZITE	11201.6 TON	10.00	112000.	.12
CONVERTER FLUX	65785.9 TON	10.00	657900.	.70
LEAD ANODE	105.6 TON	3089.00	326300.	.35
GLUE	5049.8 LB	.90	4500.	.00
GOULAC	251777.8 LB	.15	37800.	.04
H2SO4	294.1 TON	20.00	5900.	.01
LIME	10814.5 TON	53.40	577500.	.62
CITRIC ACID	174.9 TON	1360.00	237900.	.26
SODA ASH	1581.1 TON	60.00	94800.	.10
KEROSINE	283374.5 GAL	.95	269200.	.29
TOTAL			2631600.	2.82
UTILITIES				
ELECTRICITY	130854.0332 MKWHR	40.00	5234200.	5.61
NATURAL GAS, CONSUMED	4340273.7 MCF	3.15	13671900.	14.65
WATER, PROCESS	109442.4 MGAL	.34	37200.	.04
WATER, COOLING	2937374.9 MGAL	.06	176200.	.19
STEAM	1278394.1 MLB	4.22	5395000.	5.79
CREDIT FOR STEAM	1292122.2 MLB	-4.22	-5452800.	-5.84
TOTAL			19061700.	20.44
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4972000.	5.33
SUPERVISION .150			745800.	.80
TOTAL, D			5717800.	6.13
PLANT MAINTENANCE				
LABOR			4977900.	5.34
SUPERVISION .200			995500.	1.07
MATERIALS			7466700.	8.00
TOTAL, M			13440100.	14.41
PAYROLL OVERHEAD .600(PAYROLL)			7014700.	7.52
OPERATING SUPPLIES, S .200(M)			2688200.	2.88
TOTAL DIRECT COST			50554100.	54.21
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			8738400.	9.37
FIXED COST				
TAXES AND INSURANCE .020			6045700.	6.48
DEPRECIATION 12.500 YR			27902800.	29.95
TOTAL			33948500.	36.41
TOTAL ANNUAL OPERATING COST			93241000.	100.00

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE, AC
ID & CIT. PT. CU REC. = 98.2%
CU- 15. 6 6
CHANGES BASED ON UPDATED CITRATE PLANT,
KEROSENE FLOTATION

JULY 31, 1980

COPPER 99999.9 TON PER YEAR

ESTIMATE 227.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	219000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	5445000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	15540000.
TOTAL	21204000.

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(4-76)

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TABLE 39. - Summary of costs and operating personnel for conventional copper smelter with acid plant for converter and Bureau of Mines citrate plant for reverberatory

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST,		UNIT PRO-DUCTION COST,$/LB COPPER
			$	PCT	
CRUSHING AND STORAGE	19.0	20387300.	4917900.	5.27	.02459
MATTE SMELTING	53.0	68227800.	21308600.	22.85	.10654
CONVERTING	25.0	38627900.	11304800.	12.12	.05652
ANODE CASTING	17.0	13789700.	4076000.	4.37	.02038
ELECTROLYTIC REFINING	106.0	73074500.	25806000.	27.68	.12903
CONTACT ACID PLANT	12.0	42964300.	11593000.	12.43	.05797
GAS COOLING & CLEANING	2.1	8615100.	2579000.	2.77	.01290
ABSORPTION	2.1	1373300.	982600.	1.05	.00491
SULFUR PRECIPITATION	4.2	554600.	358200.	.38	.00179
SULFUR RECOVERY	2.1	4971900.	1512700.	1.62	.00756
H2S GENERATION	4.3	11759200.	8240500.	8.84	.04120
SODIUM SULFATE REMOVAL	2.2	1551500.	561700.	.60	.00281
TOTAL, T		285897100.			
INITIAL REAGENTS, IR = 46900.					
FACILITIES,.100(T-IR)		28585000.			
UTILITIES,.120(T-IR)		34301900.			
TOTAL FIXED CAPITAL		348784000.			
WORKING CAPITAL		21204000.			
TOTAL CAPITAL	249.0	369988000.	93241000.	100.00	.46621

```
CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE, AC
     ID & CIT. PT.  CU REC. = 98.2%
            CU- 15.  & G
CHANGES BASED ON UPDATED CITRATE PLANT,
     KEROSENE FLOTATION

               JULY 31, 1980

      13.03940, $/ TON     CU CONCENTRATE
      63.68000, $/ TON     MATTE
     112.59481, $/ TON     BLISTER CU
      40.59660, $/ TON     BLISTER CU
     258.06026, $/ TON     COPPER
      50.85764, $/ TON     SULFURIC ACID
        .04934, $/ MSCF    FLUE GAS,1.82% SO2
      26.10306, $/ TON     SULFUR
       9.51569, $/ TON     SULFUR
      40.18532, $/ TON     SULFUR
     102.98087, $/ TON     H2S
     145.54264, $/ TON     GLAUBER SALT




COPPER                  99999.9 TON   PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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EPA-287 (Cin.)
(4-76)

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TABLE 40. - Summary of energy requirements for conventional copper smelter with acid plant for converter and Bureau of Mines citrate plant for reverberatory

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE, AC
ID & CIT. PT. CU REC. = 98.2%
CU- 15. 6 G
CHANGES BASED ON UPDATED CITRATE PLANT,
KEROSENE FLOTATION
JULY 31, 1980

COPPER 99999.9 TON PER YEAR

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8815.	.15
MATTE SMELTING	1512387.	25.90
CONVERTING	459151.	7.86
ANODE CASTING	160762.	2.75
ELECTROLYTIC REFINING	1688611.	28.92
CONTACT ACID PLANT	543706.	9.31
GAS COOLING & CLEANING	35890.	.61
ABSORPTION	106785.	1.83
SULFUR PRECIPITATION	10879.	.19
SULFUR RECOVERY	52334.	.90
H2S GENERATION	1229699.	21.06
SODIUM SULFATE REMOVAL	29280.	.50
TOTAL FOR PLANT	5838300.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	193747.	3.32
ELECTRICITY INT V	995190.	17.05
ELECTRICITY LINE V	185031.	3.17
NATURAL GAS	4340274.	74.34
STEAM	1789752.	30.66
STEAM	-1808971.	-30.98
LIMESTONE	3201.	.05
QUARTZITE	470.	.01
CONVERTER FLUX	3158.	.05
LEAD ANODE	2852.	.05
GLUE	101.	.00
GOULAC	5036.	.09
H2SO4	244.	.00
LIME	91923.	1.57
CITRIC ACID	1749.	.03
SODA ASH	28935.	.50
KEROSINE	5611.	.10
TOTAL FOR PLANT	5838300.	100.00

UNIT ENERGY REQUIREMENT 58.3831 MMBTU PER TON COPPER

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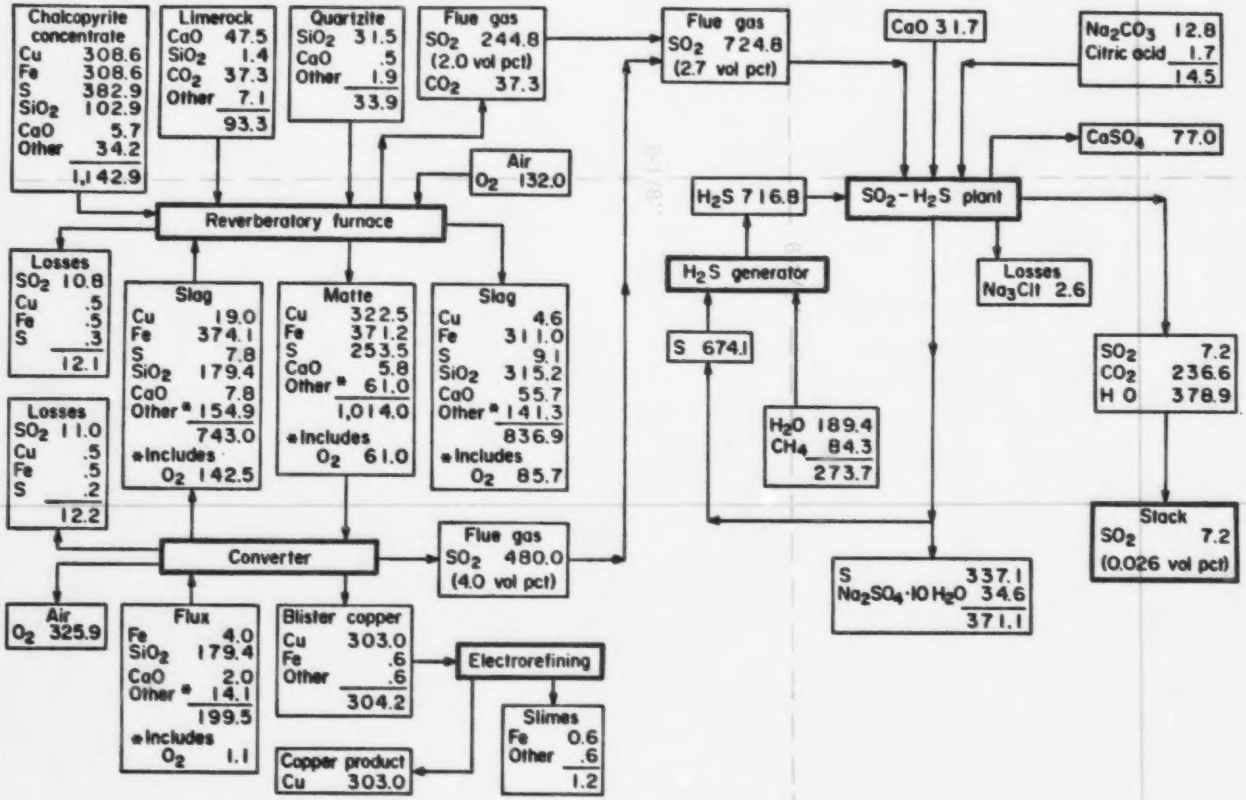
Chalcopyrite concentrate
Cu 308.6
Fe 308.6
S 382.9
SiO2 102.9
CaO 5.7
Other 34.2
1,142.9
Limerock
CaO 47.5
SiO2 1.4
CO2 37.3
Other 7.1
93.3
Quartzite
SiO2 31.5
CaO .5
Other 1.9
33.9
Flue gas
SO2 244.8
(2.0 vol pct)
CO2 37.3
Air
O2 132.0
Reverberatory furnace
Losses
SO2 10.8
Cu .5
Fe .5
S .3
12.1
Slag
Cu 19.0
Fe 374.1
S 7.8
SiO2 179.4
CaO 7.8
Other* 154.9
743.0
*Includes
O2 142.5
Matte
Cu 322.5
Fe 371.2
S 253.5
CaO 5.8
Other* 61.0
1,014.0
*Includes
O2 61.0
Slag
Cu 4.6
Fe 311.0
S 9.1
SiO2 315.2
CaO 55.7
Other* 141.3
836.9
*Includes
O2 85.7
Losses
SO2 11.0
Cu .5
Fe .5
S .2
12.2
Converter
Flue gas
SO2 480.0
(4.0 vol pct)
Air
O2 325.9
Flux
Fe 4.0
SiO2 179.4
CaO 2.0
Other* 14.1
199.5
*Includes
O2 1.1
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Electrorefining
Slimes
Fe 0.6
Other .6
1.2
Copper product
Cu 303.0
Flue gas
SO2 724.8
(2.7 vol pct)
CaO 31.7
Na2CO3 12.8
Citric acid 1.7
14.5
CaSO4 77.0
H2S 716.8
SO2-H2S plant
H2S generator
Losses
Na3Cit 2.6
S 674.1
H2O 189.4
CH4 84.3
273.7
SO2 7.2
CO2 236.6
H O 378.9
Stack
SO2 7.2
(0.026 vol pct)
S 337.1
Na2SO4·10 H2O 34.6
371.1

FIGURE 15.-Material balance and flow diagram for conventional copper smelter with a Bureau of Mines citrate process plant for the converter and reverberatory gases. (tons per day)

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TABLE 41. - Annual operating cost, $, of unit operations for conventional copper smelter with Bureau of Mines citrate plant for converter and reverberatory

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	PCT
DIRECT COST				
MATERIALS				
LIMESTONE	30775.9 TON	10.00	307800.	.31
QUARTZITE	11201.6 TON	10.00	112000.	.11
CONVERTER FLUX	65785.9 TON	10.00	657900.	.67
LEAD ANODE	105.6 TON	3089.00	326300.	.33
GLUE	5049.8 LB	.90	4500.	.00
GOULAC	251777.8 LB	.15	37800.	.04
H2SO4	294.1 TON	20.00	5900.	.01
LIME	10484.1 TON	53.40	559900.	.57
CITRIC ACID	556.2 TON	1360.00	756500.	.77
SODA ASH	4219.4 TON	60.00	253100.	.26
KEROSINE	837492.3 GAL	.95	795600.	.80
TOTAL			3817300.	3.87
UTILITIES				
ELECTRICITY	106806.1377 MKWHR	40.00	4272200.	4.33
NATURAL GAS, CONSUMED	6891623.7 MCF	3.15	21708600.	21.97
WATER, PROCESS	86192.5 MGAL	.34	29300.	.03
WATER, COOLING	7747741.5 MGAL	.06	464900.	.47
STEAM	1717833.9 MLB	4.22	7249400.	7.35
CREDIT FOR STEAM	1753435.5 MLB	-4.22	-7399500.	-7.49
TOTAL			26324900.	26.66
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4732400.	4.79
SUPERVISION .150			709900.	.72
TOTAL, D			5442300.	5.51
PLANT MAINTENANCE				
LABOR			4774700.	4.84
SUPERVISION .200			954800.	.97
MATERIALS			7161900.	7.25
TOTAL, M			12891400.	13.06
PAYROLL OVERHEAD .600(PAYROLL)			6703100.	6.79
OPERATING SUPPLIES, S .200(M)			2578400.	2.61
TOTAL DIRECT COST			57757400.	58.50
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			8364800.	8.47
FIXED COST				
TAXES AND INSURANCE .020			5820100.	5.90
DEPRECIATION 12.500 YR			26774700.	27.13
TOTAL			32602800.	33.02
TOTAL ANNUAL OPERATING COST			98725000.	100.00

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE,
CITRATE PROCESS CU REC.=98.2%
CU- 15. 4 6
CHANGES BASED ON UPDATED CITRATE PLANT,
KEROSENE FLOTATION

JULY 31, 1980

COPPER 99999.9 TON PER YEAR

ESTIMATE 217.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	318000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	5996000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	16454000.
TOTAL	22768000.

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TABLE 42. - Summary of costs and operating personnel for conventional copper smelter with Bureau of Mines citrate plant for converter and reverberatory

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20387300.	4916400.	4.98	.02458
MATTE SMELTING	53.0	68227800.	21226600.	21.50	.10613
CONVERTING	25.0	38627900.	11263400.	11.41	.05632
ANODE CASTING	17.0	13789700.	4061800.	4.11	.02031
ELECTROLYTIC REFINING	106.0	73411300.	25562000.	25.89	.12781
GAS COOLING & CLEANING	2.1	15950200.	4879900.	4.94	.02440
ABSORPTION	2.1	2562900.	2369700.	2.40	.01185
SULFUR PRECIPITATION	4.2	1294800.	586600.	.59	.00293
SULFUR RECOVERY	2.1	10001400.	3311300.	3.35	.01656
H2S GENERATION	4.3	27140400.	19522100.	19.77	.09761
SODIUM SULFATE REMOVAL	2.2	2975500.	1025200.	1.04	.00513
TOTAL, T		274369200.			
INITIAL REAGENTS, IR = 201500.					
FACILITIES,.100(T-IR)		27416800.			
UTILITIES,.120(T-IR)		32900000.			
TOTAL FIXED CAPITAL		334686000.			
WORKING CAPITAL		22768000.			
TOTAL CAPITAL	237.0	357454000.	98725000.	100.00	.49363

CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE,
CITRATE PROCESS CU REC.=98.2%
CU- 15. 4 6
CHANGES BASED ON UPDATED CITRATE PLANT,
KEROSENE FLOTATION

JULY 31, 1980

13.03542, $/ TON	CU CONCENTRATE
63.43494, $/ TON	MATTE
112.18247, $/ TON	BLISTER CU
40.45517, $/ TON	BLISTER CU
255.62026, $/ TON	COPPER
.03763, $/ MSCF	FLUE GAS,2.19% SO2
19.79384, $/ TON	SULFUR
4.89981, $/ TON	SULFUR
27.65892, $/ TON	SULFUR
163.06594, $/ TON	SULFUR
89.71286, $/ TON	GLAUBER SALT

COPPER 99999.9 TON PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

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TABLE 43. - Summary of energy requirements for conventional copper smelter with Bureau of Mines citrate plant for converter and reverberatory

```
----------------------------------------------------------------------
                                               MMBTU/YR  PERCENT
----------------------------------------------------------------------
UNIT OPERATION
  CRUSHING     AND STORAGE                        8815.      .11
  MATTE        SMELTING                        1512307.    18.52
  CONVERTING                                    459151.     5.62
  ANODE        CASTING                          160762.     1.97
  ELECTROLYTIC REFINING                        1657857.    20.30
  GAS COOLING & CLEANING                        174409.     2.14
  ABSORPTION                                    301061.     3.69
  SULFUR   PRECIPITATION                         31515.      .39
  SULFUR       RECOVERY                         148988.     1.82
  H2S          GENERATION                      3633583.    44.49
  SODIUM SULFATE REMOVAL                         78251.      .96
----------------------------------------------------------------------
    TOTAL FOR PLANT                            8166781.   100.00

ENERGY SOURCE
  ELECTRICITY LOW V                             301621.     3.69
  ELECTRICITY INT V                             634813.     7.77
  ELECTRICITY LINE V                            185031.     2.27
  NATURAL GAS                                  6891624.    84.39
  STEAM                                        2404967.    29.45
  STEAM                                       -2454810.   -30.06
  LIMESTONE                                       3201.      .04
  QUARTZITE                                        470.      .01
  CONVERTER FLUX                                  3158.      .04
  LEAD ANODE                                      2852.      .03
  GLUE                                             101.      .00
  GOULAC                                          5036.      .06
  H2SO4                                            244.      .00
  LIME                                           89115.     1.09
  CITRIC ACID                                     5562.      .07
  SODA ASH                                       77214.      .95
  KEROSINE                                       16502.      .20
----------------------------------------------------------------------
    TOTAL FOR PLANT                            8166781.   100.00

UNIT ENERGY REQUIREMENT     81.6679 MMBTU PER  TON  COPPER
```

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CRUSH, STORE, SMELT, CONVERT, ELECTROREFINE,
     CITRATE PROCESS CU REC.=98.28
             CU- 15.  4 6
CHANGES BASED ON UPDATED CITRATE PLANT,
     KEROSENE FLOTATION
             JULY 31, 1980

COPPER                        99999.9 TON   PER YEAR
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--Roasted Feed With Roaster and Converter Gases to Acid Plant

The final scenario consists of a conventional smelter in which the feed to the reverberatory furnace is preroasted in a fluidized bed roaster that burns off 33.4 percent of the 382.9 tons per day of sulfur in the feed. The reverberatory furnace burns off another 20 percent of the sulfur which is emitted as 1.5 percent SO_2 and is vented up the stack. Another 41.3 percent of the sulfur is burned off in the converter. The roaster and converter offgas streams are combined and go to a 1,050-ton-per-day capacity double-contact acid plant that recovers 823.0 tons of byproduct acid per day. This modification recovers 70.16 percent of the sulfur in the feed as acid. The balance of the sulfur is distributed as follows, in percent: 2.38 in slag, 2.98 as leakage within the smelter (2.85 as fugitive gas and 0.13 as fugitive dust and fume), 3.74 as neutralized acid sludge, and 20.74 up the stack (20.00 as reverberatory furnace offgas and 0.74 as acid plant offgas). A materials balance flowsheet for this process is shown in Figure 16, and costs and energy requirements are presented in Tables 44 through 46.

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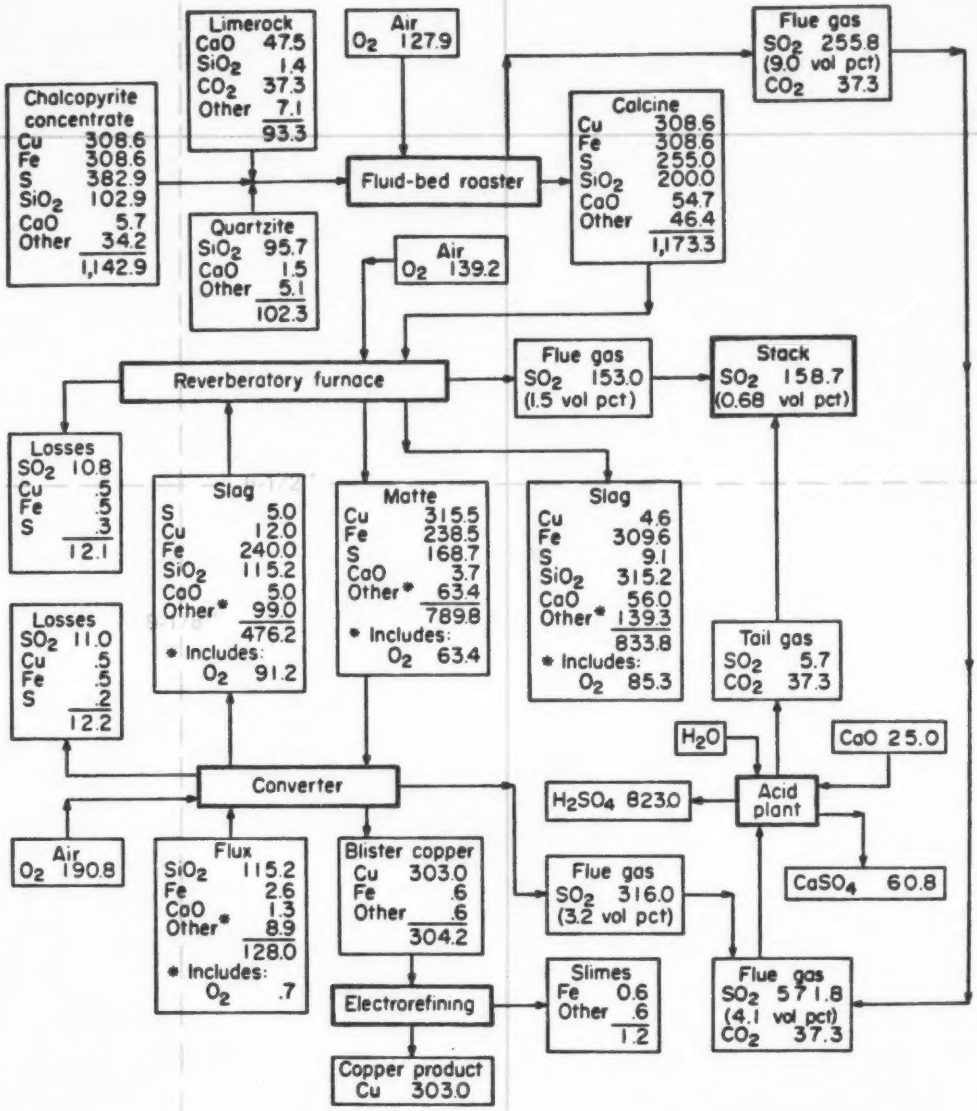
Limerock
CaO 47.5
SiO2 1.4
CO2 37.3
Other 7.1
93.3
Air
O2 127.9
Flue gas
SO2 255.8
(9.0 vol pct)
CO2 37.3
Chalcopyrite concentrate
Cu 308.6
Fe 308.6
S 382.9
SiO2 102.9
CaO 5.7
Other 34.2
1,142.9
Fluid-bed roaster
Calcine
Cu 308.6
Fe 308.6
S 255.0
SiO2 200.0
CaO 54.7
Other 46.4
1,173.3
Quartzite
SiO2 95.7
CaO 1.5
Other 5.1
102.3
Air
O2 139.2
Reverberatory furnace
Flue gas
SO2 153.0
(1.5 vol pct)
Stack
SO2 158.7
(0.68 vol pct)
Losses
SO2 10.8
Cu .5
Fe .5
S .3
12.1
Slag
S 5.0
Cu 12.0
Fe 240.0
SiO2 115.2
CaO 5.0
Other* 99.0
476.2
* Includes:
O2 91.2
Matte
Cu 315.5
Fe 238.5
S 168.7
CaO 3.7
Other* 63.4
789.8
* Includes:
O2 63.4
Slag
Cu 4.6
Fe 309.6
S 9.1
SiO2 315.2
CaO 56.0
Other* 139.3
833.8
* Includes:
O2 85.3
Losses
SO2 11.0
Cu .5
Fe .5
S .2
12.2
Tail gas
SO2 5.7
CO2 37.3
H2O
CaO 25.0
Converter
H2SO4 823.0
Acid plant
Air
O2 190.8
Flux
SiO2 115.2
Fe 2.6
CaO 1.3
Other* 8.9
128.0
* Includes:
O2 .7
Blister copper
Cu 303.0
Fe .6
Other .6
304.2
Flue gas
SO2 316.0
(3.2 vol pct)
CaSO4 60.8
Electrorefining
Slimes
Fe 0.6
Other .6
1.2
Flue gas
SO2 571.8
(4.1 vol pct)
CO2 37.3
Copper product
Cu 303.0

FIGURE 16.- Material balance and flow diagram for conventional copper smelter with concentrate roasting and an acid plant for roaster and converter gases. (tons per day)

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(4-76)

TABLE 44. - Annual operating cost, $, of unit operations for conventional copper smelter with a roaster using an acid plant for roaster and converter

	ANNUAL CONSUMPTION	UNIT COST	OPERATING COST, $	PCT
DIRECT COST				
MATERIALS				
LIMESTONE	23971.2 TON	10.00	239700.	.30
QUARTZITE	8724.9 TON	10.00	87200.	.11
CONVERTER FLUX	65785.9 TON	10.00	657900.	.82
LEAD ANODE	105.6 TON	3089.00	326300.	.41
GLUE	5049.8 LB	.90	4500.	.01
GOULAC	251777.8 LB	.15	37800.	.05
H2SO4	294.1 TON	20.00	5900.	.01
LIME	8270.0 TON	53.40	441600.	.56
TOTAL			1800900.	2.27
UTILITIES				
ELECTRICITY	134775.0156 MKWHR	40.00	5391000.	6.80
NATURAL GAS, CONSUMED	2916690.5 MCF	3.15	9187600.	11.58
WATER, PROCESS	109442.9 MGAL	.34	37200.	.05
WATER, COOLING	207900.0 MGAL	.06	12500.	.02
STEAM	1053600.0 MLB	4.22	4446300.	5.61
CREDIT FOR STEAM	1213168.9 MLB	-4.22	-5119600.	-6.45
TOTAL			13955000.	17.61
DIRECT LABOR				
LABOR 9.600/MAN HOUR			4632600.	5.85
SUPERVISION .150			694800.	.87
TOTAL, D			5327400.	6.72
PLANT MAINTENANCE				
LABOR			4383700.	5.53
SUPERVISION .200			876700.	1.11
MATERIALS			6575300.	8.29
TOTAL, M			11835700.	14.93
PAYROLL OVERHEAD .600(PAYROLL)			6352600.	8.02
OPERATING SUPPLIES, $ .200(M)			2367200.	2.99
TOTAL DIRECT COST			41638800.	52.54
INDIRECT COST				
ADMINISTRATION AND OVERHEAD .400(D+M+S)			7812100.	9.86
FIXED COST				
TAXES AND INSURANCE .020			5239900.	6.61
DEPRECIATION 12.500 YR			24566200.	30.99
TOTAL			29806100.	37.61
TOTAL ANNUAL OPERATING COST			79257000.	100.00

CRUSH, STORE, ROAST, SMELT, CONVERT, ELECTROREF
INE, ACID PT., CU REC. = 98.2%
CU- 15. 3 6
12.5 YR DEPRECIATION
BASED ON ASARCO COSTS

JULY 31, 1980

COPPER 99999.9 TON PER YEAR

ESTIMATE 200.0 MAINT. MEN, 10.560/MAN HOUR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH

WORKING CAPITAL

1 MONTH'S SUPPLY OF MATERIALS = (TOTAL ANNUAL MATERIAL COST)/12	150000.
1 MONTH'S OUT-OF-POCKET EXPENSE = (TOTAL AN OP COST-DEPRECIATION)/12	4558000.
2 MONTH'S PRODUCT INVENTORY = (TOTAL ANNUAL OPERATING COST)/6	13210000.
TOTAL	17918000.

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(4-76)

TABLE 45. - Summary of costs and operating personnel for conventional copper smelter with roaster using an acid plant for roaster and converter

	NUMBER OF OPERATORS	CAPITAL COST, $	ANNUAL OPERATING COST, $	ANNUAL OPERATING COST, PCT	UNIT PRODUCTION COST, $/LB COPPER
CRUSHING AND STORAGE	19.0	20387300.	4920000.	6.21	.02460
MATTE SMELTING	53.0	68008000.	20881700.	26.35	.10441
CONVERTING	25.0	38627900.	11408900.	14.39	.05704
ANODE CASTING	17.0	13789700.	4117600.	5.20	.02059
ELECTROLYTIC REFINING	106.0	73089600.	26585900.	33.54	.13293
CONTACT ACID PLANT	12.0	37799900.	11342900.	14.31	.05671
TOTAL, T		251702400.			
FACILITIES,.100(T)		25170200.			
UTILITIES,.120(T)		30204400.			
TOTAL FIXED CAPITAL		307077000.			
WORKING CAPITAL		17918000.			
TOTAL CAPITAL	232.0	324995000.	79257000.	100.00	.39629

```
CRUSH, STORE, ROAST, SMELT, CONVERT, ELECTROREF
     INE, ACID PT., CU REC. = 98.2%
            CU- 15.  3 6
12.5 YR DEPRECIATION
     BASED ON ASARCO COSTS

              JULY 31, 1980

      13.04497, $/ TON    CU CONCENTRATE
      80.11886, $/ TON    MATTE
     113.63163, $/ TON    BLISTER CU
      41.01093, $/ TON    BLISTER CU
     265.85926, $/ TON    COPPER
     *********, $/ TON    SULFURIC ACID


COPPER                  99999.9 TON   PER YEAR

U. S. BUREAU OF MINES, SALT LAKE CITY, UTAH
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EPA-287 (Cin.)
(4-76)

TABLE 46. - Summary of energy requirements for conventional copper smelter with roaster using an acid plant for roaster and converter

	MMBTU/YR	PERCENT
UNIT OPERATION		
CRUSHING AND STORAGE	8815.	.21
MATTE SMELTING	1334976.	31.84
CONVERTING	459151.	10.95
ANODE CASTING	160762.	3.83
ELECTROLYTIC REFINING	1684719.	40.18
CONTACT ACID PLANT	544552.	12.99
TOTAL FOR PLANT	4192976.	100.00
ENERGY SOURCE		
ELECTRICITY LOW V	128445.	3.06
ELECTRICITY INT V	1101662.	26.27
ELECTRICITY LINE V	185031.	4.41
NATURAL GAS	2916690.	69.56
STEAM	1475040.	35.18
STEAM	-1698437.	-40.51
LIMESTONE	2493.	.06
QUARTZITE	366.	.01
CONVERTER FLUX	3158.	.08
LEAD ANODE	2852.	.07
GLUE	101.	.00
GOULAC	5036.	.12
H2SO4	244.	.01
LIME	70295.	1.68
TOTAL FOR PLANT	4192976.	100.00

UNIT ENERGY REQUIREMENT 41.9298 MMBTU PER TON COPPER

CRUSH, STORE, ROAST, SMELT, CONVERT, ELECTROREF
INE, ACID PT., CU REC. = 98.28
CU- 15. 3 6
12.5 YR DEPRECIATION
BASED ON ASARCO COSTS
JULY 31, 1980

COPPER 99999.9 TON PER YEAR

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APPENDIX A

OTHER PROCESSES EXAMINED

HECLA-EL PASO ROASTING-HYDROMETALLURGICAL PROCESS

The Hecla-El Paso process was an integrated scheme for treating chalcopyrite flotation concentrate and oxidized copper ore. This process was developed for a particular ore body with separate zones of oxide and sulfide copper. A flowsheet for the entire process is shown in Figure 17. The chalcopyrite concentrate was given a sulfating roast to solubilize the copper which was recovered by leaching and electrowinning. Offgas from the roasting operation was used to make acid which was combined with spent electrolyte from electrowinning and used for vat leaching of the oxide ore. Residue from the roasted and leached chalcopyrite, rich in iron, was reduced to sponge iron in a rotary kiln and used to recover copper from the vat leach liquor by cementation. This process facilitated the recovery of the precious metals contained in the concentrate since they ended up in the cement copper.

The process was designed to avoid environmental degradation on the Papago Indian Reservation, and there were no significant emissions containing toxic elements. Roaster gases, which had the potential of carrying arsenic, all went to a sulfuric acid plant where they were thoroughly cleaned. All process steps were tested on a pilot plant scale[20] at the Hazen research facilities in Golden, Colo. The commercial plant started operating in 1975 but was shut down before its rated production capacity was attained because of depressed copper prices.

ARBITER PROCESS

In the Arbiter process,[21] a vigorously agitated slurry of copper concentrate in an aqueous ammoniacal medium is treated with oxygen under ambient conditions. Copper and sulfur are both oxidized and solubilized, copper as an ammoniacal sulfate complex [$Cu(NH_3)_4SO_4$] and sulfur as ammonium

---

[20] Griffith, W. A., H. E. Day, T. S. Jordan, and V. C. Nyman. Development of the Roast-Leach-Electrowin Process for Lakeshore. TMS/AIME, Chicago, Ill., Feb. 26-Mar. 1, 1973. Preprint A73-64, 20 pp.

[21] Arbiter, Nathaniel. New Advances in Hydrometallurgy. Proc. of Symp. on Efficient Use of Fuels in the Met. Ind. Sponsored by Inst. of Gas Technol., IIT Center, Chicago, Ill., Dec 9-13, 1974, pp. 661-672.

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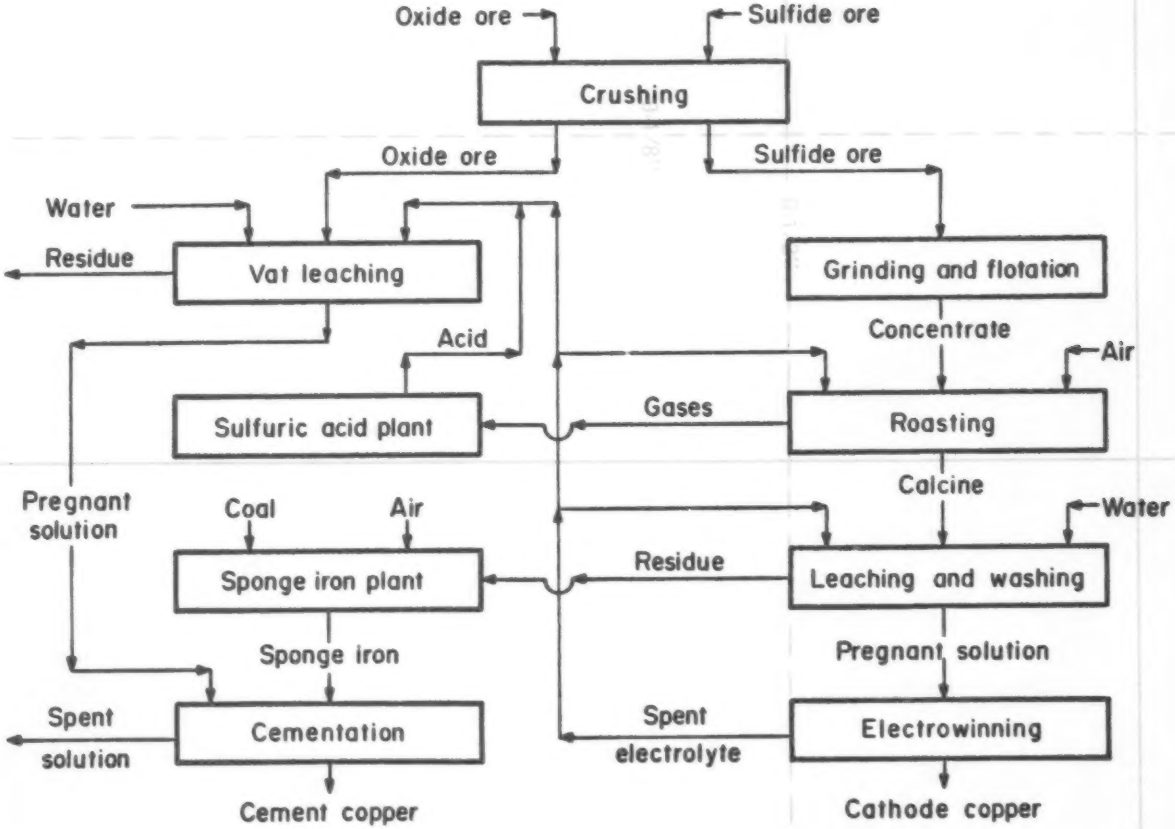
Oxide ore
Sulfide ore
Crushing
Oxide ore
Sulfide ore
Water
Residue
Vat leaching
Grinding and flotation
Acid
Concentrate
Air
Sulfuric acid plant
Gases
Roasting
Pregnant solution
Calcine
Coal
Air
Water
Sponge iron plant
Residue
Leaching and washing
Sponge iron
Pregnant solution
Spent solution
Cementation
Spent electrolyte
Electrowinning
Cement copper
Cathode copper

FIGURE 17. -Flowsheet for Lakeshore project.

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sulfate. This type of leaching has been done before,[22,23] but only at elevated temperatures and pressures. It is claimed that the use of 0.15-0.20 hp/ft^3 for agitation makes the kinetics favorable under ambient conditions.

After liquid solids separation, the pregnant ammoniacal leach solution is treated by solvent extraction and the copper is loaded onto LIX 65N. The solvent is stripped with spent electrolyte (H_2SO_4), and copper is recovered by electrowinning. Raffinate from the stripping operation contains additional ammonium sulfate, equivalent to the copper extracted. Details of the process are shown in the flowsheet in Figure 18.

In a large operation, the main byproduct, ammonium sulfate, would be produced in amounts too large for the available markets. An economical process would require the regeneration of ammonia. The flowsheet shows a treatment with lime and steam for recovery of ammonia. However, pilot plant work has demonstrated that lime can be added to the leach reactors and steam stripping can be eliminated.

The process does eliminate dust and gas pollution completely, but there remains the potential for pollution of air by ammonia and water by ammonium sulfate. There have not been any detailed reports showing how well these new sources of pollution are controlled. A 100-ton-per-day commercial-size demonstration plant operated from August 1974 to July 1975[24] and was shut down "because of production cutbacks."

A revised version of the process has been developed that eliminates solvent extraction by substituting the precipitation of copper as cuprous ammonium sulfite with sulfur dioxide gas and the subsequent thermal decomposition of the precipitate in an autoclave to yield copper powder. This version appears simpler and less energy consuming, but it still produces about the same amount of ammonium sulfate byproduct. The demonstration plant is not presently operating.

---

[22] Foreward, F. A. and V. N. Mackiw. Chemistry of the Ammonia Pressure Process for Leaching Ni, Cu, and Co From Sherritt/Gordon Sulfide Concentrates. Trans. AIME, v. 203, (1955) New York, pp. 457-463.

[23] Henderson, Thomas D., Jr. The Dissolution of Copper from Sulfide Minerals with Ammoniacal Solutions at Elevated Temperatures and Pressures. M.S. Thesis, Univ. of Ariz., 1964.

[24] Rosenzweig, Mark D. Copper Makers Look to Sulfide Hydrometallurgy. Chem. Eng., Jan. 5, 1976, pp. 79-81.

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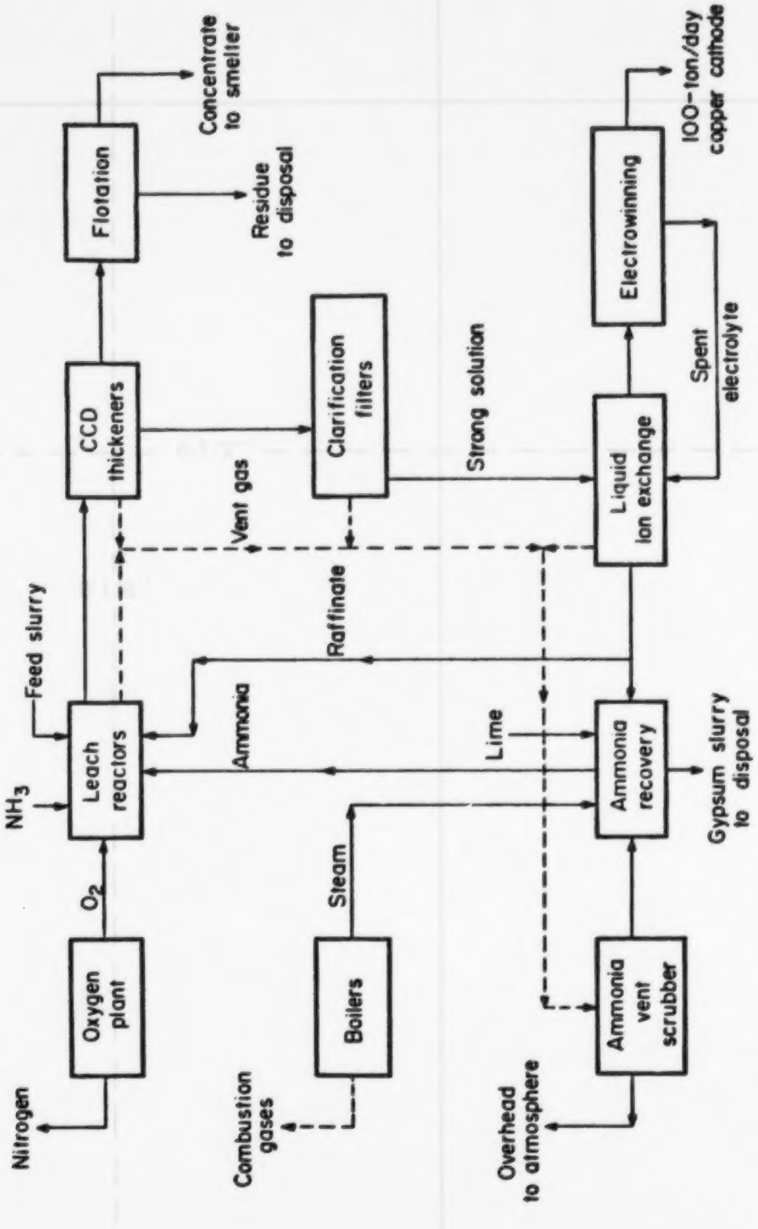
Nitrogen
Oxygen plant
O_2
NH_3
Leach reactors
Feed slurry
CCD thickeners
Flotation
Concentrate to smelter
Residue to disposal
Combustion gases
Boilers
Steam
Ammonia
Ammonia
Raffinate
Vent gas
Clarification filters
Strong solution
Overhead to atmosphere
Ammonia vent scrubber
Lime
Ammonia recovery
Gypsum slurry to disposal
Liquid ion exchange
Spent electrolyte
Electrowinning
100-ton/day copper cathode

FIGURE 18.-Flowsheet for Anaconda's arbiter process.

SHERRITT-GORDON/COMINCO PROCESS

The Sherritt-Gordon/Cominco process is based on a roast (thermal activation), leach, and electrowinning system that purportedly does not discharge any environmentally objectionable wastes. Most of the sulfur is recovered in elemental form, and the balance of the sulfur together with waste iron is rejected as an insoluble jarosite.

The process was tested in a $5,200,000, 10-ton-per-day pilot plant at Fort Saskatchewan during 1976. Details of the process,[25] the pilot plant operation,[26] and a cost estimate for a commercial operation[27] have only recently become available, too late for examination under this project.

CYMET PROCESS

The Cymet process was developed by the Cyprus Metallurgical Process Corp., in Tucson, Ariz. The original process[28] leached sulfide concentrates in two stages, the first was a conventional agitation leach in a solution containing ferric chloride and the second stage involved use of the combined action of chlorine, ferric chloride, and an electric potential in the anode compartment of an electrolytic cell. A copper powder product was recovered from the cathode compartment of the cell. The anolyte went to the first-stage leach and the catholyte to another diaphragm cell that yielded an electrolytic iron byproduct and additional ferric chloride which was recycled to the first-stage leach. A flowsheet for this process is shown in Figure 19.

The original Cymet process has been revised and is now referred to as the Cyprus Copper Process.[29] In the revised process the electrolytic cells have been eliminated, and a high-purity copper is now being produced by recovering cuprous chloride crystals from the leach solution and reducing

---

[25] Swinkels, G. M. and R. M. G. S. Berezowsky. The Sherritt-Cominco Copper Processes - Part I: The Process. CIM Bulletin, February 1978, pp. 105-121.

[26] Kawulka, P., C. R. Kirby, and G. L. Bolton. The Sherritt-Cominco Copper Process - Part II: Pilot Plant Operation. CIM Bulletin, February 1978, pp. 122-130.

[27] Maschmeyer, D. E. G., E. F. G. Milner,and B. M. Parekh. The Sherritt-Cominco Copper Process - Part III: Commercial Implications. CIM Bulletin, February 1978, pp. 131-139.

[28] Allen, E. S., P. R. Kruesi, W. C. Hazen, and D. N. Goens. Treatment of Chalcopyrite Copper Concentrate Using the Cymet Process. TMS/AIME, Dallas, Tex., February 1974. Preprint No. A74-7, 15 pp.

[29] McNamara, J. H., W. A. Ahrens, and J. G. Franek. A Hydrometallurgical Process for the Extraction of Copper. Paper pres. at AIME meeting in Denver, Colo., Feb. 26-Mar. 2, 1978. Preprint No. 78-B-90.

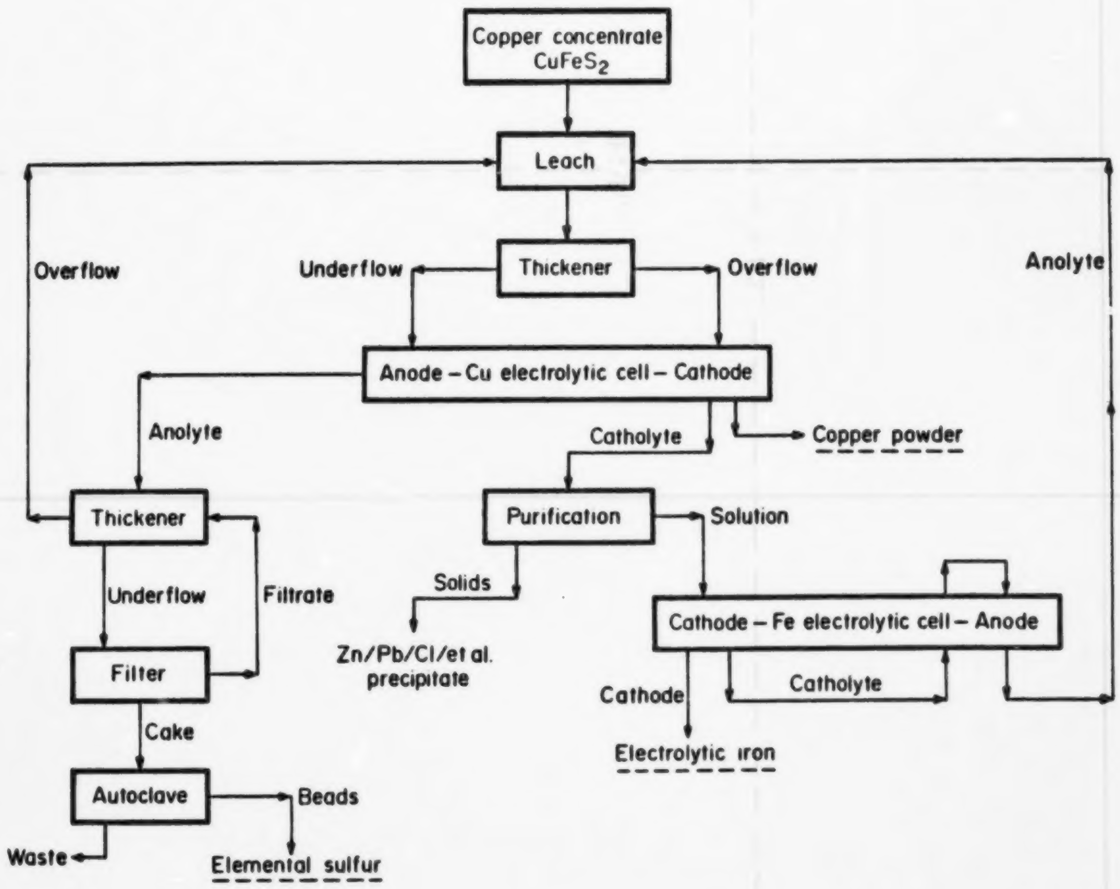
Copper concentrate $CuFeS_2$
Leach
Thickener
Underflow
Overflow
Overflow
Anolyte
Anode – Cu electrolytic cell – Cathode
Anolyte
Catholyte
Copper powder
Thickener
Purification
Solution
Solids
Underflow
Filtrate
Cathode – Fe electrolytic cell – Anode
Filter
Zn/Pb/Cl/et al. precipitate
Cathode
Catholyte
Cake
Electrolytic iron
Autoclave
Beads
Waste
Elemental sulfur

FIGURE 19. - Flowsheet for original Cymet process.

them with hydrogen in a fluidized bed. Leaching solution is regenerated, and excess iron is precipitated as jarosite by air oxidation in an autoclave. Although critical details of the process are being withheld pending patent coverage, disclosures have been made on estimates of its economics; these indicate that capital and operating costs may be competitive with smelting processes.

DUVAL "CLEAR" PROCESS

Duval's "Clear" process[30,31] is a hydrometallurgical scheme that is intended to be competitive with conventional pyrometallurgical processes. It is designed to treat sulfide concentrates without causing air pollution from sulfur dioxide emissions. CLEAR stands for "Copper Leaching Electrolysis and Regeneration."

In this process the copper in sulfide concentrates is solubilized in two leaching stages, the first in a solution containing cupric chloride and the second in a cupric chloride-ferric chloride-HCl solution under an oxygen overpressure. The first-stage leach is called the "Reduction Stage," and the solution from this leach contains copper in the form of cuprous chloride. Solubility of the cuprous chloride is increased by the addition of sodium and potassium chloride. Copper is recovered from the leach solution by electrowinning in diaphragm cells in the "Metal Recovery Stage." The cuprous chloride solution is fed into the cathode compartment, and part of the copper is reduced and deposited. It then diffuses through the diaphragm into the anode compartment where it is oxidized to cupric chloride. Anolyte from the electrowinning cells goes to the second leaching stage called "Oxidation and Regeneration-Purge Stage." In this stage, a series of complex reactions occur. The remaining copper and iron in the feed are solubilized and oxidized to the cupric and ferric states, some of the sulfur is oxidized to sulfate, and most of the ferric iron is precipitated as a jarosite. Elemental sulfur and jarosite are discharged with the tailings, and the cupric chloride solution goes to the first stage of leaching. A schematic flow diagram for the process is shown in Figure 20.

The system can effectively eliminate dust and SO_2 pollution that is usually associated with smelters. However, the published literature does not mention anything about the disposal of soluble chloride wastes. In this closed leaching system, there will eventually be a buildup of impurities that will have to be bled off. In addition, other soluble chlorides will be washed off the copper deposits and some may remain in the tailings. Since the majority of the chlorides are highly soluble, some means will have to be found to dispose of them. Duval is presently starting a 32,500-ton-per-year plant based on this process at its Esperanza mine near Tucson, Ariz. Details of the operation have not been revealed.

[30] Atwood, George E. and Charles Curtiz. (Assigned to Duval Corp., Houston, Tex.) Hydrometallurgical Process for the Production of Copper. U.S. Pat. 3,785,944, Jan. 15, 1974.

[31] ______. (Assigned to Duval Corp., Houston, Tex.) Hydrometallurgical Process for the Production of Copper. (Revised). U.S. Pat. 3,879,272, Apr. 22, 1974.

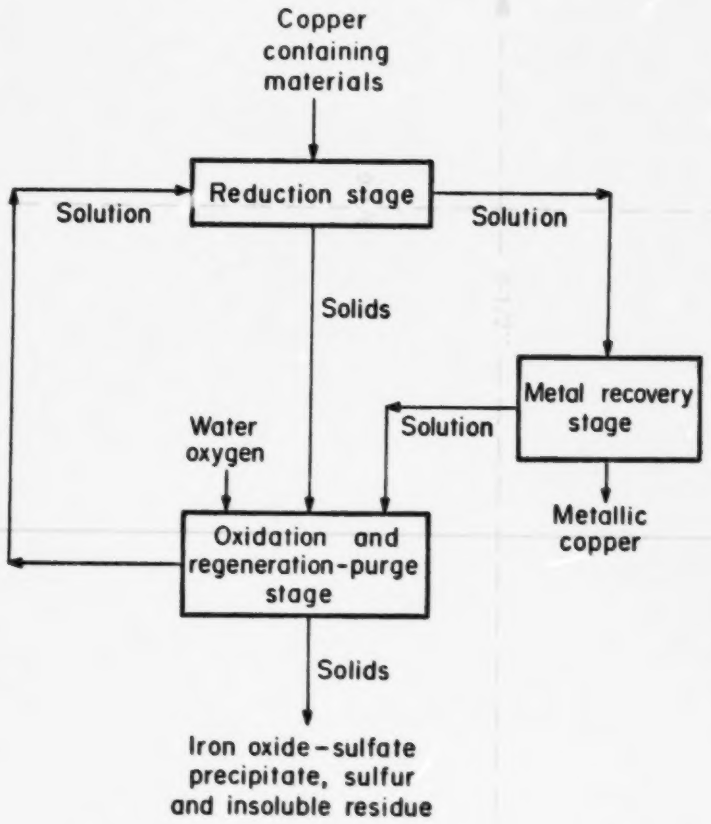
Copper
containing
materials
Reduction stage
Solution
Solution
Solids
Metal recovery
stage
Solution
Water
oxygen
Oxidation and
regeneration-purge
stage
Metallic
copper
Solids
Iron oxide-sulfate
precipitate, sulfur
and insoluble residue

FIGURE 20. - Flowsheet of Duval's "CLEAR" process.

MITSUBISHI THREE-FURNACE PROCESS

The three-furnace continuous smelting process[32-34] was developed by Mitsubishi Metal Corp. of Japan. This process is basically similar to the flash smelting process but it uses three interconnected furnaces, (1) a smelting furnace, (2) a slag cleaning furnace, and (3) a converting furnace. This arrangement simplifies the operation by eliminating the batchwise transfer of molten matte and reducing the manpower requirements. A schematic illustration of the furnace arrangement is shown in Figure 21.

Concentrate, converter slag, flux, and air are injected into the molten bath of the smelting furnace with lances; matte and slag from the smelting furnace overflow into an electrically heated settling furnace where additions of coke and pyrite are made to clean the slag. Slag containing 0.4 to 0.5 percent copper overflows and is granulated and discharged. A high-grade matte containing 60 to 65 percent copper is siphoned from the bottom into the converting furnace. In the converting furnace, oxygen-enriched air and limestone flux are injected into the surface with lances and the matte is converted into blister copper containing less than 0.05 percent sulfur. Blister copper is siphoned off the bottom and slag is overflowed to a granulating and drying operation and recycled to the smelting furnace. The entire operation is under control of a computer.[35]

Offgases from this process, containing 12 to 15 percent sulfur dioxide, go through a waste heat boiler, a precipitator, and a sulfuric acid plant. Dust carryover, about 3 to 4 percent of the charged concentrate, is similar to that of a reverberatory furnace because of the efficient capture of the injected feed by the turbulent bath in the smelting furnace. Volatile impurities[36] are contained in the dust. The dust is usually recycled with the feed, but if the impurity level is high, the dusts are treated separately.

---

[32] Suzuki, T. and T. Nagano. Development of New Continuous Copper Smelting Process. Paper pres. at MMIJ/AIME Meeting in Tokyo, Japan, May 27, 1972. (Also reviewed in Eng. and Min. J., August 1972, pp. 66-68.)

[33] Rutledge, Peter. Mitsubishi Metal Previews Its Promising New Continuous Copper Smelting Process. Eng. and Min. J., December 1975, pp. 88-89.

[34] Themelis, N. J. Impact of Energy and Environment Constraints on Copper Smelting. Min. Eng., January 1976, pp. 42-46.

[35] Suzuki, T., I. Ohyama, and T. Shibazaki. Computer Control in Mitsubishi Continuous Copper Smelting and Converting Process. TMS/AIME, Dallas, Tex., February 1974. Preprint No. A74-14, 21 pp.

[36] Suzuki, T., T. Shibazaki. Behavior of Impurities in Mitsubishi Continuous Smelting and Converting Process. TMS/AIME, Ann. Meeting, New York, February 1975. Preprint No. A75-40, 15 pp.

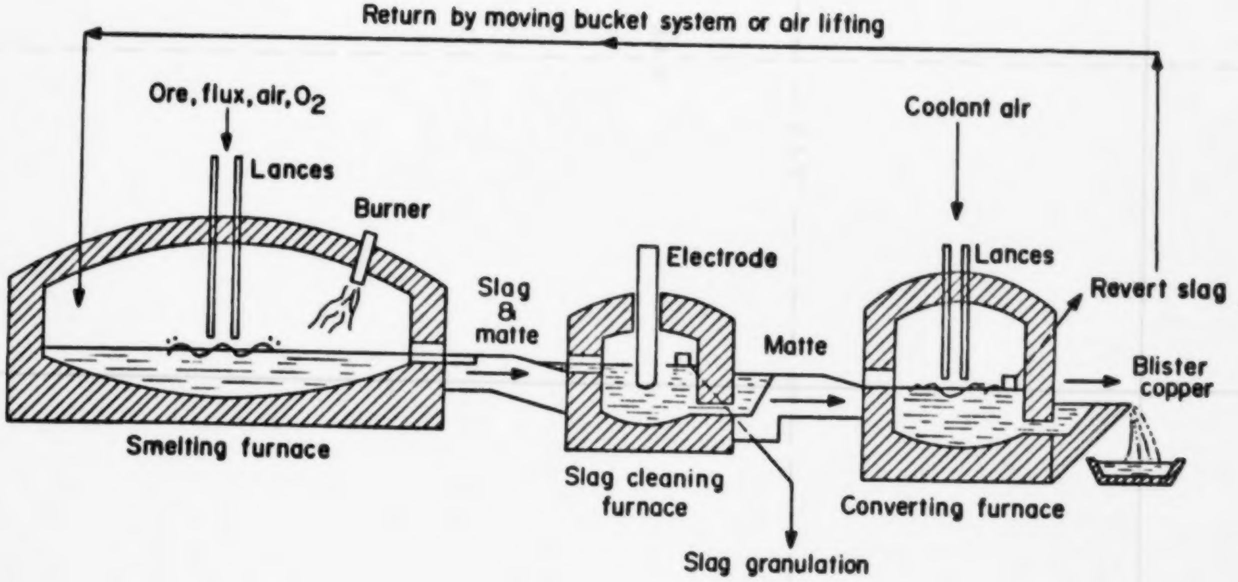
Return by moving bucket system or air lifting
Ore, flux, air, O_2
Lances
Burner
Electrode
Coolant air
Lances
Revert slag
Slag & matte
Matte
Blister copper
Smelting furnace
Slag cleaning furnace
Converting furnace
Slag granulation

FIGURE 21.- Schematic diagram of Mitsubishi's three-furnace process

The Japanese plant has a capacity of 550 tons of concentrates per day and is located on Naoshima Island in Japan's Seto Inland Sea. Another plant about three times larger in capacity is being built by Texasgulf, Inc., at their Kidd Creek operation in Timmons, Ontario.

OXYGEN-ENRICHED REVERBERATORY FURNACE PROCESS

The use of oxygen in reverberatory smelting operations has been reported for actual applications[37-41] and for theoretical studies.[42]

These reports indicate that oxygen enrichment of the combustion air and/or the usage of oxy-fuel roof burners increase the smelting rates by 25 to 50 percent and an additional 3 to 8 tons of charge can be smelted for every ton of oxygen. The melt temperature is also raised, thus improving separation of the matte and reducing metal losses but at the expense of decreased refractory life. Offgas volume is reduced, and the SO_2 content of the gas can be increased to 2.0 to 2.5 percent.

At present, oxygen is being used in reverberatory furnaces at the Onahama Smelter in Japan, and construction is in progress on new reverberatory smelters that will use oxygen at the Chuquicamato and El Teniente smelters in Chile. At the El Teniente smelter the new operation will use 380 metric tons of oxygen per day and copper production is expected to increase from 160,000 to 254,000 metric tons per year. In all of these smelters the main objective is to increase copper smelting capacity.

It is too early to determine whether the other theoretical benefits, less gas volume, less SO_2 and dust emission, and increased acid making capacity, will be realized.

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[37] Saddington, E., W. Curlock, and P. Queneau. Tonnage Oxygen for Nickel and Copper Smelting at Copper Cliff. J. of Metals, v. 18, April 1966, pp. 440-452.

[38] Kupryakov, Y. D., et al. East European Metal Rev., v. 1, No. 2, July 1969, pp. 26-29.

[39] Niimura, M. Japanese Copper Smelter Strives for SO_2 Emission Control. Eng. and Min. J., v. 73, No. 8, August 1972, pp. 60-71.

[40] Itakura, K., H. Ikeda, and M. Goto. Double Expansion of Onahama Smelter and Refinery. Pres. at Ann. AIME Meeting, Dallas, Tex., Feb. 23-28, 1974.

[41] Dayton, Stanley. Chile Where Major New Copper Output Can Materialize Faster Than Anyplace Else. EMJ November 1979, pp. 68-111.

[42] Wrampe, P., and E. C. Nillman. Oxygen Utilization in Copper Reverberatory Furnaces: Theory and Practice. TMS/AIME, Dallas, Tex., Feb. 23-28, 1974. Preprint No. A74-258, 18 pp.

CONVERTER SMELTING

Smelting of concentrate directly to blister copper in converters has been practiced in Japan[43] and in the United States.[44] The Hitachi Smelter in Japan successfully practiced converter smelting between 1956 and 1972 and completely eliminated the reverberatory smelting operation. In their process, pelletized concentrate and oxygen-enriched air were charged to converters. A satisfactory grade of blister copper was produced, but the slag volume was large since it contained all the impurities that are usually contained in a reverberatory slag. The larger quantity of slag had to be milled to recover copper for recycle. Since 1972, Hitachi has been using a flash smelter.

Kennecott's Utah Copper Division attempted to bypass part of the reverberatory operation by feeding loose concentrates into their converters and blowing with oxygen-enriched air. However, their dust losses were high, and the practice was discontinued. Kennecott has recently undergone a modernization program, in which Noranda-type furnaces are now being used for direct smelting to a high grade matte.

Although converter smelting can yield an acid grade SO_2, it has drawbacks that make alternate smelting processes more attractive to the industry.

TOP BLOWN ROTARY CONVERTER (TBRC) SMELTING

The top blown rotary converter is a rotatable refractory-lined vessel that can be tilted through 360° for filling, blowing, or emptying. During operation it is rotated at about 40 revolutions per minute and tilted at an angle between 15° and 20°. A water-cooled lance, positioned through the top, blows air, oxygen, oxygen-enriched air or any combination of these with fuel onto the surface of the melt in order to oxidize or reduce the charge. An illustration of the converter is shown in Figure 22.

Among the advantages claimed for the converter are excellent gas-solid-liquid contact, rapid mixing of the charge, uniform heat distribution, and higher operating temperatures. It is also claimed that it can reduce the capital investment for a small smelter by eliminating the matte smelting operation.

[43] Kamedo, Mitsuo, Tohoku University, Japan. History of Copper Smelting in Japan. Joint meeting MMIJ-AIME, Tokyo, Japan, May 1972. Preprint No. G1113, 20 pp.

[44] Utah Copper Div. Will Use Oxygen in Its Copper Smelting Process. Eng. and Min. J., January 1968, p. 116.

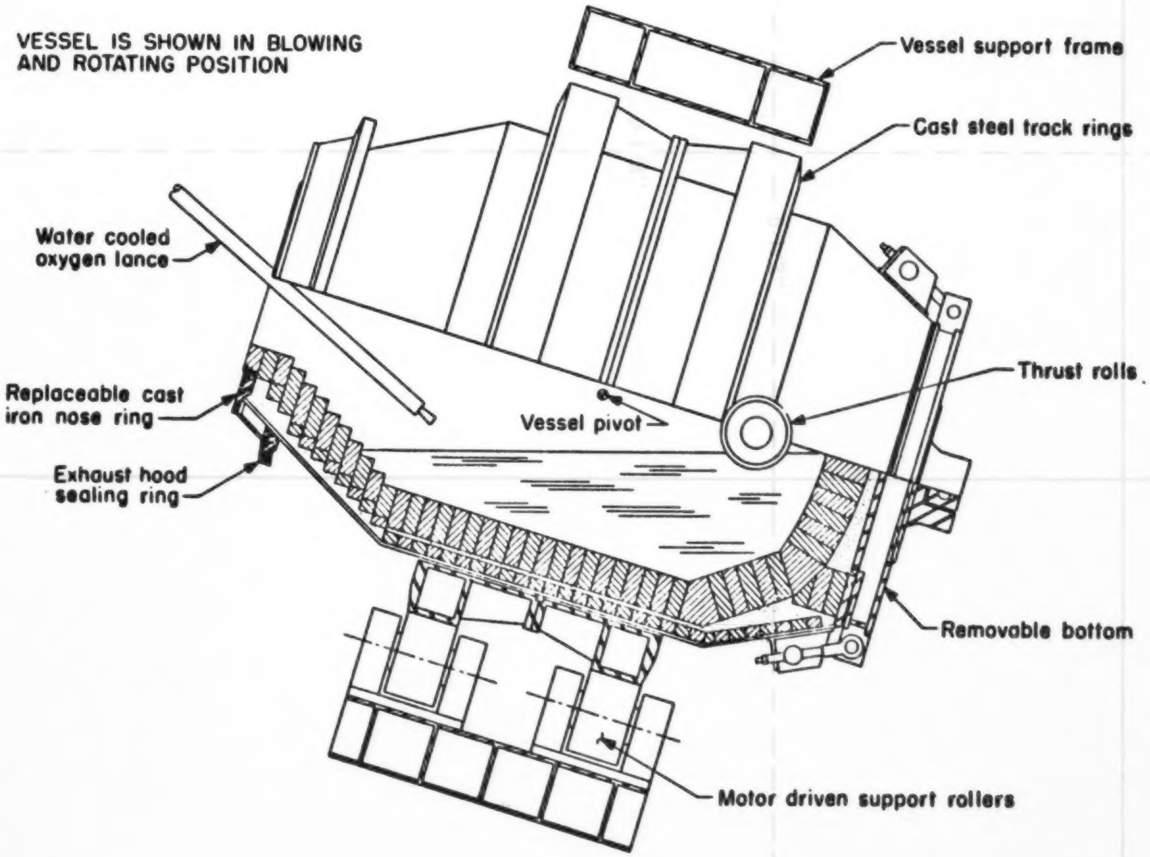
VESSEL IS SHOWN IN BLOWING AND ROTATING POSITION
Vessel support frame
Cast steel track rings
Water cooled oxygen lance
Thrust rolls
Replaceable cast iron nose ring
Vessel pivot
Exhaust hood sealing ring
Removable bottom
Motor driven support rollers

FIGURE 22. - Pictorial sketch of TBRC converter.

Over 95 percent of the oxygen is utilized and exhaust gases can average over 50 percent SO_2. Rapid mixing in the turbulent melt facilitates the mixing and melting of all sizes of charge including fine concentrates. The high operating temperature makes the smelting reaction proceed faster, and a more effective volatilization of bismuth and other minor impurities is claimed. Since most of the offgases are acid grade, they would all be cleaned in the sulfuric acid plant and there would not be any significant emissions.

When used for the direct conversion of concentrate, this unit overcomes the dusting problem that was encountered when direct conversion was attempted in conventional converters. A charge of fine feed can be thoroughly melted and mixed by the rotating action of the hot converter before blowing. In addition, a uniform high temperature can be maintained even with sulfur-deficient charges by introduction of oxygen and fuel through the blowing lance.

This converter is currently being used by International Nickel Co., at Copper Cliff, Ontario, for smelting white metal produced from nickel sulfide concentrates by conventional reverberatory and converter smelting. It is also being used by Boliden for lead fuming at their RÖNNSKÄR WORKS in Skelleftenhamn. Proposals were made on use of this converter for production of copper using cement copper, white metal, matte, or copper sulfide concentrate as feed,[45] and actual tests were made on copper concentrates at International Nickel's Copper Cliff facility.[46]

At present, no major smelter is using the TBRC for copper production, but Afton Mines, Ltd. of Canada is planning to use one to produce 25,000 tons per year of blister copper[47] at a smelter that will be built near their mine in Kamloops, British Columbia. The ore that will be used contains a high percentage of native copper, and Afton reports that the process is particularly suited to this type of concentrate.

REVERBERATORY SMELTING WITH DMA SO_2 PROCESS

The DMA SO_2 process uses an organic solvent known as dimethylaniline to absorb sulfur dioxide from dilute gas streams. Thermal stripping of the solvent with steam yields a concentrated gas that can be dried, liquified, and stored.

[45] Daniele, R. A., and L. H. Jaguay. TBRC, A New Smelting Technique. Pres. at Ann. AIME Meeting, San Francisco, Calif., February 1972.

[46] Daniele, R. A., and L. H. Jaguay. Full Scale TBRC Smelting Tests on Copper Concentrate. Paper pres. at Ann. AIME Meeting, Dallas, Tex., Feb. 24-28, 1974.

[47] British Columbian Copper Mine/Smelter Project. Min. Magazine, December 1975, pp. 719-721.

The actual process is more complex because it includes provisions for scrubbing SO_2 in the absorber offgas with soda ash, scrubbing of solvent vapor with dilute H_2SO_4, and regeneration of solvent by neutralization of acid scrubbing solution with soda ash. All of the steps in this process are illustrated in a schematic flowsheet in Figure 23.

When used on a conventional copper smelter, the DMA process should be able to use dilute gases from the reverberatory furnace, and the liquified SO_2 it recovers can be used together with converter gases to make acid. However, the DMA process needs at least 2.0 percent SO_2 to be economical; otherwise, steam requirements for the treatment of the large volumes of DMA would be excessive. Both the reverberatory and converter gases would have to be thoroughly cleaned, and the process has the potential of removing virtually all of the trace impurities and dust.

Dimethylaniline processes have been previously used at the Falconbridge Nickel Co. plant in Kristiansand, Norway,[48] and at the American Smelting and Refining Co. (ASARCO) in Selby, Calif., but the gases treated contained more than 3.5 percent SO_2.

At present there is only one DMA process plant in operation. The ASARCO-Tacoma smelter uses a DMA plant to concentrate and liquify SO_2 from converters in a copper smelting operation. The recovered SO_2 is marketed as a liquid.

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[48] Fleming, E. P., and T. C. Fitt. Ind. Eng. Chem., 42 (11), pp. 2253-2258 (1950).

[49] Henderson, James M. and J. B. Pfeiffer. Liquid SO_2 From Copper Converter Gases-The ASARCO Dimethylaniline Process. Paper No. 45C Pres. at 78th Nat. Meeting AIChE, Salt Lake City, Utah, Aug. 18-21, 1974

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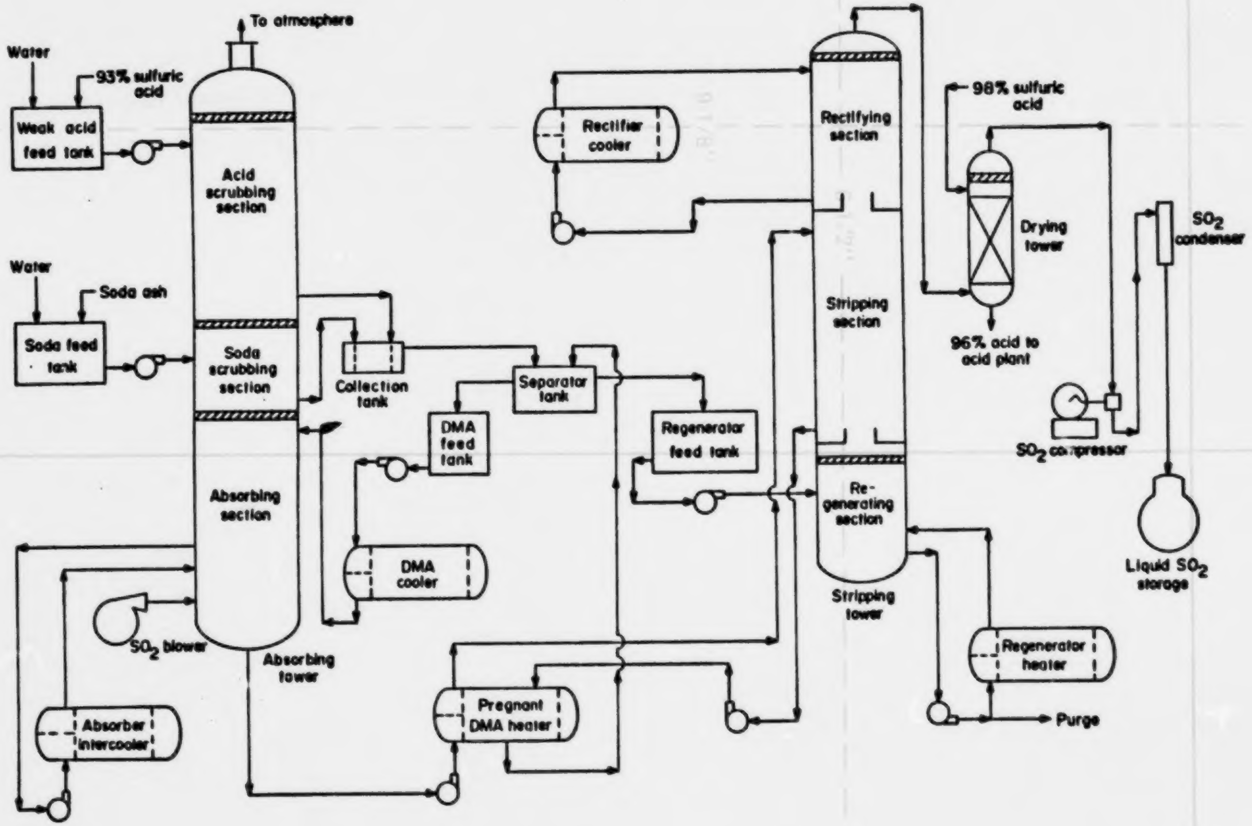
To atmosphere
Water
93% sulfuric acid
Weak acid feed tank
Acid scrubbing section
Water
Soda ash
Soda feed tank
Soda scrubbing section
Collection tank
Absorbing section
SO2 blower
Absorbing tower
Absorber intercooler
DMA feed tank
DMA cooler
Separator tank
Regenerator feed tank
Pregnant DMA heater
Rectifier cooler
Rectifying section
Stripping section
Re-generating section
Stripping tower
98% sulfuric acid
Drying tower
96% acid to acid plant
SO2 condenser
SO2 compressor
Liquid SO2 storage
Regenerator heater
Purge

FIGURE 23.-Schematic flowsheet for DMA SO_2 absorption plant.

APPENDIX B

COST ESTIMATION BASIS

BASIS FOR ESTIMATION OF CAPITAL COSTS

Capital costs, including direct construction costs, indirect costs, interest during construction, cost of facilities and utilities, and working capital costs, were projected to midyear for 1980 (Marshall and Swift index estimated at 655.0). These costs were calculated with the aid of an in-house computer program that is being prepared for publication as a Bureau of Mines Information Circular (IC). Capital costs are accurate to ±30 percent. Capital cost information for unit operations and entire smelters is given in the appendixes.

Direct Construction Cost

Direct construction costs consist of the delivered cost of equipment, labor cost to erect the equipment, material and labor costs for construction of special equipment at the plant site, and the cost of additional construction required to support, house, and protect the equipment and make it operable. Equipment costs are obtained from direct quotes by suppliers, records of similar construction, equipment catalogs and published cost estimating data. Delivery costs based on weight, type of equipment, and average distance to suppliers are added.

Costs of equipment requiring additional construction to make it operable and those for occasional items of equipment not requiring this construction are included. Construction costs, which include foundations, structures, buildings, etc., are estimated by factors applied to the total delivered cost of the equipment requiring such construction. These factors vary with the types of unit operation and have been accumulated from detailed consideration of requirements as new types of unit operations are encountered.

Indirect Cost

The indirect cost is taken to be 69 percent of the direct cost and approximates the addition of 13.5 percent for field indirect expense plus the following percentages of successive resulting subtotals: 7.5 for engineering, 7.5 for administration and overhead, 20 for contingencies, and 7.5 for contractor's fee. The field indirect expense covers field supervision, inspection, temporary construction equipment rental, and payroll overhead.

Interest

Interest cost during the construction period is the sum of direct and indirect construction costs multiplied by a factor that is actually 0.70 times the product of interest rate and construction period in years. From a combination of information in the literature and that obtained from a review of actual construction records, it appears that the average amount paid to the contractor over the construction period is about 70 percent of the contract price. For these estimates an 11.0 percent interest rate was assumed.

Special Supplies and Equipment

Costs for mobile equipment and initial reagents, such as citric acid, which can be purchased at the end of construction, are added to the total construction cost to obtain the total fixed capital cost for each unit operation.

Plant Facilities

Plant facilities cost, which includes buildings and equipment for office, laboratory, shops, and warehouses, plus fencing, roads, railroad spurs, fire protection facilities, and safety equipment, is estimated as 10 percent of the total fixed capital cost of the production units of the plant.

Utilities

Plant utilities cost, which includes the cost of construction and equipment necessary to conduct utilities to the plant from an outside source and to distribute them to the various buildings or operating units of the plant, is estimated as 12 percent of the total fixed capital cost of production units.

Working Capital

Working capital is estimated as the sum of 1 month's supply of raw materials, 1 month's out-of-pocket expense, and 2 month's product inventory.

BASIS FOR ESTIMATION OF OPERATING COSTS

Annual operating costs are based on 330 operating days per year for all processes except for the Noranda in which case 330 days per year were used only for the electrorefining operating while the other unit operations used 274 days per year. These costs are reported on the basis of charges against the entire plant.

The cost of raw materials includes the shipping cost. For these estimates no costs were assigned to the chalcopyrite concentrate so that only the processing cost is determined.

Utility requirements are calculated for the unit operations and totaled for the integrated plant. Rates for the integrated plant are those charged by the utility companies and were assumed to be $0.040 per kilowatt hour for electricity, $3.15 per thousand cubic feet for natural gas, $0.34 per thousand gallons for process water, and $0.06 per thousand gallons for cooling water. The rate for steam was assumed to be $4.22 per thousand pounds, but in all cases the requirements were supplied by package and waste heat boilers. Credit was given for excess steam assuming that the smelter would be located adjacent to a plant that could utilize the steam.

Direct labor includes operating labor and supervision. Labor cost is based on a wage rate of $9.60 per hour. Labor requirements were estimated on the basis of 4.2 men for each position requiring continuous operation. Supervison is taken as 15 percent of the labor cost.

Plant maintenance consists of maintenance labor, supervision, and maintenance materials. Labor varies between 2 and 3 percent of the fixed capital cost without interest, depending on the nature of the unit operation. Supervision is 20 percent of the labor cost, and material cost is assumed to be equal to the labor cost except for processes using the Bureau of Mines citrate process which requires a larger maintenance material cost.

Payroll overhead is estimated as 60 percent of the cost of labor and supervision for operation and maintenance.

Operating supplies are assumed equal to 20 percent of the cost of maintenance.

Indirect costs include the cost of maintaining the plant facilities and utilities, the expense of accounting, control and research laboratories, engineering, plant protection and safety, warehousing, shipping and the executive and administrative offices. These costs for the general plant are estimated as 40 percent of the cost of labor, maintenance, and operating supplies. For the unit operations, other prorated charges make the percentage a little higher.

Taxes and insurance are estimated as 2 percent of the fixed capital cost without interest.

Depreciation is estimated on the basis of straight-line depreciation over a life of 12.5 years (8 percent per year).

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APPENDIX C

HYPOTHETICAL STANDARD COPPER CONCENTRATE

The composition of the hypothetical copper concentrates used as a standard in this report was based on the arithmetical average of analyses of four copper concentrates, one from Utah and three from Arizona. This average was altered slightly to simplify calculations by (1) eliminating Al_2O_3 analysis and redistributing the percentages and (2) rounding off to the nearest 0.5 percent. Analyses of the four concentrates, their averages, and the hypothetical composition are shown in Table 47.

TABLE 47. ANALYTICAL DATA USED TO ESTABLISH A HYPOTHETICAL COPPER CONCENTRATE STANDARD

	Composition, pct						
	Cu	Fe	S	SiO_2	Al_2O_3	CaO	Other
1st concentrate	15.4	31.0	36.9	11.0	4.3	-	1.4
2nd concentrate	30.0	24.7	30.0	9.4	1.73	0.11	4.06
3rd concentrate	30.0	28.2	33.5	4.8	2.2	0.4	0.9
4th concentrate	31.8	24.2	27.8	6.9	1.7	1.8	5.8
Average	26.8	27.03	32.05	8.03	2.48	0.58	3.04
Standard selected	27.0	27.0	33.5	9.0	-	0.5	3.0

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